

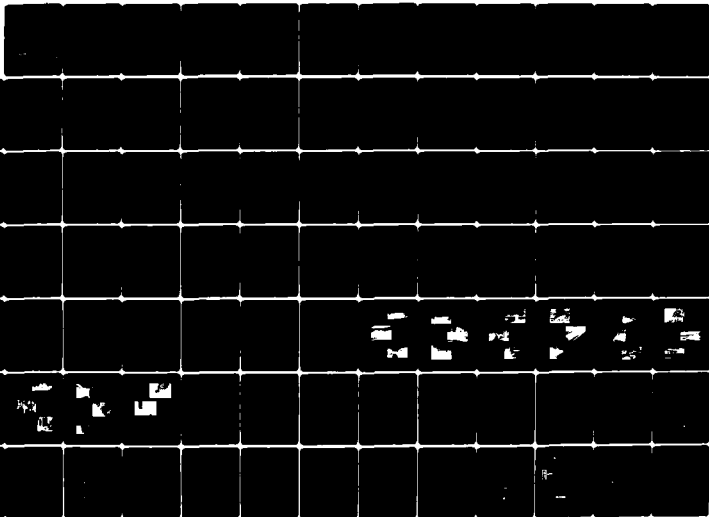
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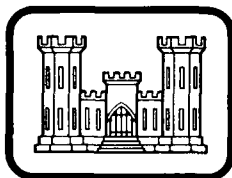
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MISCELLANEOUS PAPER GL-80-19

STORAGE OF RESIDUAL FUEL OIL IN UNDERGROUND UNLINED ROCK CAVERNS

by

Don C. Banks

Geotechnical Laboratory
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December 1980

Final Report

Approved For Public Release; Distribution Unlimited

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Prepared for U. S. Army Engineer Division, Huntsville
Huntsville, Alabama 35807

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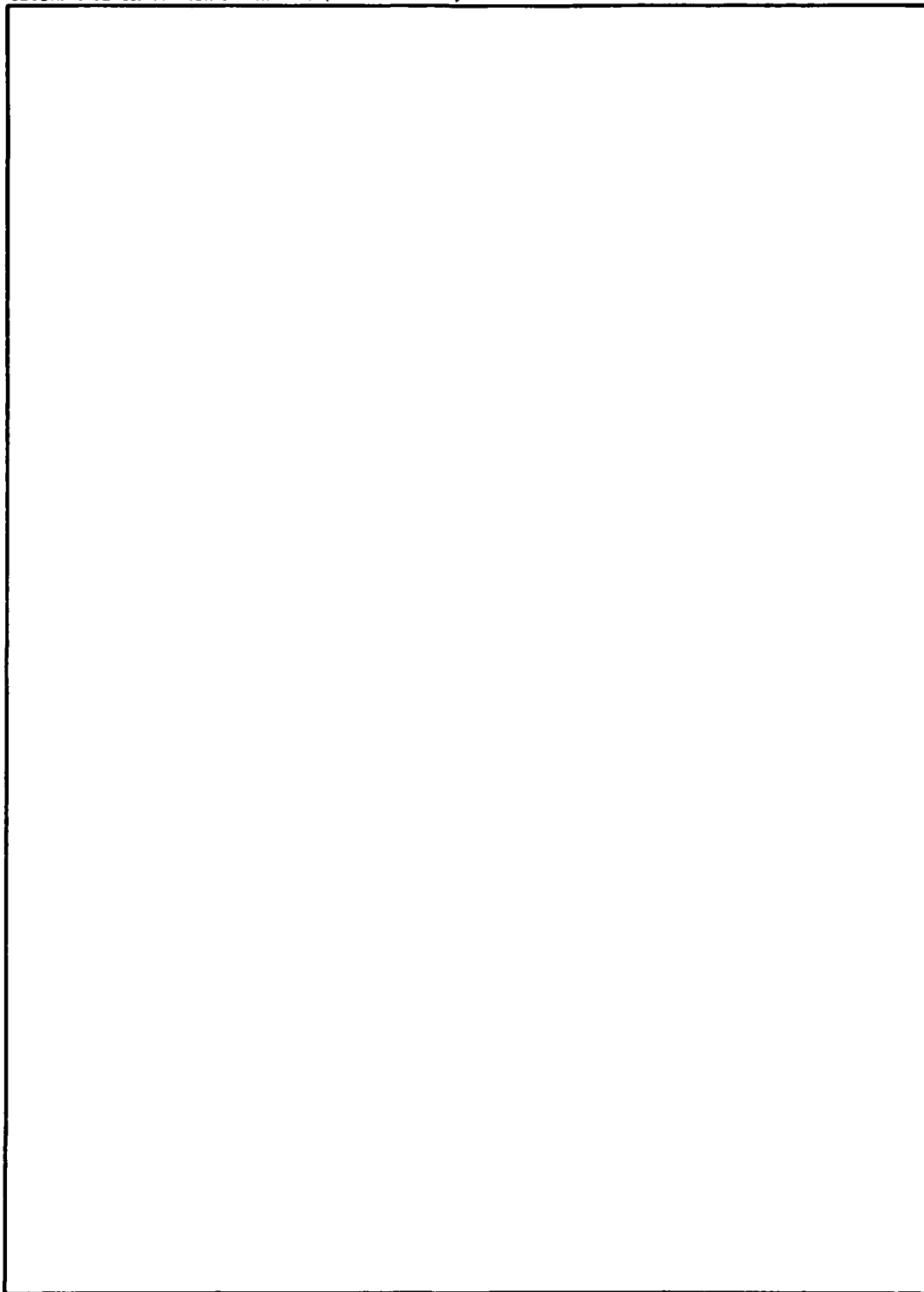
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Preface

This report contains a narrative summary of information gained from discussions with several prominent individuals involved in geotechnical investigations, as well as design and construction of unlined rock chambers for underground storage of residual fuel oil. The discussions were held during a visit to Finland and Sweden from 15 to 29 June 1980 by Dr. D. C. Banks, Chief of the Engineering Geology and Rock Mechanics Division, U. S. Army Engineer Waterways Experiment Station (WES). In Finland, he met with officials of Finncavern Ltd. Arrangements for those meetings were made possible by Mr. Antero Hakapaa, Finncavern Ltd., Mr. Stig Johansson, Neste Oy, and Mr. Osmo Kettunen, Counselor for Science and Technology, Embassy of Finland. In Sweden, he met with officials of several companies, notably SKANSKA and GEOSTOCK, who were exhibitors at ROCKSTORE 80.

Funds for the trip were provided by the U. S. Department of Energy, the National Academy of Sciences, and the CWIS Materials-Rock Research Program. However, the report is sponsored by the U. S. Army Engineer Division, Huntsville.

COL Nelson P. Conover, CE, was the Commander and Director of the WES during the time of the trip and preparation of this report. Mr. Fred R. Brown was the Technical Director.

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STORAGE OF RESIDUAL FUEL OIL IN
UNDERGROUND UNLINED ROCK CAVERNS

Background

1. In 1975, The Congress of the United States passed the Energy Policy and Conservation Act (EPCA), which created a Strategic Petroleum Reserve (SPR) in which crude oil could be stored for use in the event of a major interruption of the orderly acquisition of foreign oil. Later, in 1979, the President recommended that part of the proceeds from the Windfall Profits Tax resulting from deregulation of the oil industry be used to establish a Regional Petroleum Reserve (RPR) for the east coast of the United States and noncontiguous storage in Puerto Rico and Hawaii. The Department of Energy (DOE) is preparing, for submission to the Congress, an amendment to the SPR plan that will allow implementation of the RPR. The amendment will provide that revenues from the Windfall Profits Tax pay the incremental costs of program planning, developing, and maintaining local facilities for regional and noncontiguous storage as follows:

a. East Coast (DOE Regions 1-4): 20 million barrels (bbl) of residual fuel oil (No. 6), or an acceptable substitute for residual fuel oil, will be stored. A minimum of 10 million bbl of this storage will be physically located in the northeastern portion of the United States.

b. Hawaii: 3 million bbl of petroleum (2.3 million bbl of crude oil and 0.7 million bbl of kerosene jet fuel) will be stored.

c. Puerto Rico: 1.3 million bbl of petroleum (0.8 million bbl of crude oil and 0.5 million bbl of unfinished naphtha) will be stored.

Baseline planning for the RPR was initiated for each location during 1979. Among the several items being investigated during planning were site locations and the type of storage media. A more detailed discussion of the SPR and RPR can be found elsewhere.²

² Strategic Petroleum Reserve - Annual Report - 16 February 1980, DOE/RA-0047, U. S. Department of Energy.

2. To help solve major technical problems in the SPR program, additional resources from other Government agencies were committed to the DOE in 1979. The U.S. Army Corps of Engineers (CE) was one such agency, which, through a Master Interagency agreement (March 1979), will provide professional, technical, and managerial services in support of the SPR. Further needs of the DOE (in baseline planning for the RPR) led to additional agreements between the DOE and the CE. The majority of the planning efforts in support of the RPR within the CE was assigned to the U.S. Army Engineer (USAE) Division, Huntsville (HND). The HND, in turn, has requested assistance from the USAE Waterways Experiment Station (WES). In one completed study (Larson, 1980),* the WES described the deleterious effects of long-term storage of crude oil and petroleum products and suggested products and process modifications to minimize or eliminate the negative effects of such storage. In a second study, the WES was asked to perform a generic study of four storage media: steel tanks (aboveground), buried concrete tanks (cut-and-cover), mines (either abandoned or specially constructed), or solutioned caverns (salt domes) for use in storage of the residual fuel oil along the east coast of the United States. In the study, the relative technical and cost/benefit merits of the various options were to be assessed. The study was started on 12 May 1980 but was put "on hold" on 2 June 1980. (More recent information indicates that the study may not be resumed until possibly FY 83, i.e., 1 October 1982.)

3. While the storage media study was only in the initial stages when put "on hold," results had already indicated that little if any information was available on United States experiences in storage of No. 6 residual fuel oil in underground caverns. This technique has been successfully used in Europe, particularly Finland and Sweden, for a number of years. The technique has been described in numerous technical papers, but direct contacts with technical personnel had been limited.

* Larson, R. J., 1980. "Additives to Prevent Deleterious Effects Associated with Long-Term Storage of Petroleum Products," USAE Waterways Experiment Station (Report to USAE Division, Huntsville, in press).

4. The author was scheduled to go to Stockholm, Sweden, as the official United States delegate to the Council Meeting of the International Society of Rock Mechanics (ISRM), on 22 June 1980. Travel and limited per diem support was provided by the National Academy of Science/ National Research Council in connection with the author's role as Chairman of the U.S. National Committee for Rock Mechanics. The Council Meeting of the ISRM had been scheduled for Stockholm to coincide with ROCKSTORE 80, an international symposium organized to discuss the use of underground space for environmental protection, low-cost storage, and energy savings. Since such discussion is of continued interest to the CE, the necessary permission and funding was obtained from the CE to allow the author to attend ROCKSTORE 80. Upon learning of the planned visit to Sweden, officials in DOE and HND encouraged the author to precede the Stockholm visit with a visit to Finland to obtain information concerning the use of underground storage for residual fuel oil in that country. Funds for the additional week were made available from the storage media study.

Purpose

5. This report is written to document the findings from the visit to Finland and Sweden. Literature obtained from the visit is cited in the report but the documents themselves are on file in the Engineering Geology and Rock Mechanics Division (EGRMD) of the Geotechnical Laboratory (GL). This report plus the file of literature will be used directly once the media study is reactivated. Cited items are available for loan to interested parties.

Organization

6. A narrative summary of technical items is given in the text of the report. Appendix A contains the daily report of contacts and discussions from 15-29 June 1980. Appendix B contains pertinent photographs taken during the visit. Appendix C contains a bibliographic listing of

source materials that are cited in the text as Bibl: 1, etc. Appendix D contains names, addresses, telephone numbers, etc., of persons contacted during this visit.

Technical Data

7. References to volume measurements are expressed in terms of both barrels and cubic metres throughout the report. For example, a barrel contains 42 gallons (gal);* a cubic metre (m^3) contains 35.3 cubic feet (f^3). Therefore,

$$1 m^3 = 6.287 \text{ bbl (accurate)}$$

For convenience sake, any conversions will use $1 m^3$ or approximately 6 bbl (nominal).

* I always wondered why. In keeping with the term synchronicity suggested by Jung in his book, Man and His Symbols (1964), I ran across an article in the International Herald Tribune, 24 June 1980, entitled "A Barrel of Oil is Nothing More than a Measure," (UPI) Washington, which stated that the oil barrel, a source of measurement whenever the Organization of Petroleum Exporting Countries decides to raise prices of its crude, does not really exist.

But if it did, it would hold 42 gal.

Yesterday Henry Lartigue, Jr., Exxons's Public Affairs Manager, said: "The standard barrel is merely an arbitrary unit of measure. It's a holdover from the infancy of the oil business. Oil is not shipped in 42-gal units."

In fact, the standard barrel may never have existed, at least in the same literal sense as the ubiquitous 55-gal drum. In the early oil days, customers carted their purchases away in their own barrels, which probably varied widely in size, according to Mr. Lartigue.

In 1866, some West Virginia producers decided to end the confusion by agreeing to sell no crude oil by the barrel or package but by the gallon only and to make an allowance of 2 gal on the gauge of each and every 40 gal in favor of the buyer.

Thus, the 42-gal "barrel" was born, although the 55-gal drum became the standard container. Today, large quantities of oil--like Saudi Arabia's production--are regularly measured in mythical barrels.

8. The report centers on No. 6 residual fuel oil. The following table lists the material properties of the fuel oil presently under consideration for storage along the east coast of the United States.

General Information

No. 6 Residual or Heavy Fuel Oil Specification

Grade (ASTM)	6
Specific Gravity, 60/60°F	0.910-0.993
Saybolt Viscosity,	
Universal at 38°C (100°F)	---
Furol at 50°C (122°F)	(50-250)
Kinematic Viscosity, cSt	
At 38°C (100°F)	---
At 50°C (122°F)	(103-530)
Flash Point, °C (°F), Min.	66(150)
Pour Point, °C (°F), Max.	16(60)
Ash, Wt %, Max.	0.1
Water and Sediment, by	1.0
Centrifuge, Vol %, Max.	
or:	
Water by Distillation, Vol %, Max.	1.0
and:	
Sediment by Extraction, Wt %, Max.	0.1
Sulphur, Wt %, Max.	2.7
Compatibility Rating (D 2781), Max.	2.0
Ramshottom Carbon Residue, Wt %, Max.	15.0
Asphaltenes (IP 143), Wt %, Max.	15.0
Additives	NONE

Note: Supplied by the Huntsville Division (from Larson, 1980 (previously cited on p. 2)).

Information Obtained

Present and past usage

9. While nationalistic pride of who was first and who had the most or biggest was never an issue for debate during the visit, it is interesting to note that the United States was an initial leader in underground storage of oil. The U.S. Navy's Red Hill storage facility in Hawaii was planned in 1938 and was completed in 1943. This 6-million-bbl facility has 20 vertical concrete-lined vaults above the water table (Bibl: 1c). While the United States effort could be considered somewhat venturesome, Sweden started to investigate in 1937 the possibilities for underground storage of oil products. This effort was encouraged by past successful experiences with underground storage of compressed air. The investigations proved that concrete lining on rock walls below the groundwater table was fully tight against the loss of petroleum products when water fully filled up the pores in the lining. Toward the end of the 1940's an abandoned feldspar mine in the Stockholm archipelago was used to store heavy fuel oil. This experience encouraged the conversion of a number of abandoned mines into oil storage caverns. During the 1940's, a number of new chambers were specially constructed in which steel liners and a fluctuating water bed were used to store various oil products. In 1950, the state of the art had advanced sufficiently that an unlined rock cavern was constructed at Edholm for the storage of gasoline. According to L. S. Jones (Bibl: 1c), "The good experience gained during a number of years of storage in unlined caverns has resulted in the present practice to store both heavy oil products and gasoline on water beds in unlined rock caverns." It is without merit to compare the Finnish experiences or developments against those cited for the Swedish. Both countries developed techniques and capabilities as dictated by national needs. Both countries, which are dependent upon oil imports, have critical (winter) seasons in which the need for energy is so great and during which importation is so difficult (or almost impossible) that large volumes of stored oil or oil products are required. Also, both

nations aggressively pursue industrialization that necessitates the optimization of refinery operation and the storage of many refined oil products.

10. These needs, coupled with the engineering creed of solving a problem in the safest, most cost-effective, and most environmentally acceptable manner, have led to the development of widespread use and acceptance of underground-unlined chambers for the storage of oil and oil products.

11. Similar needs and developments have not existed in the United States. While an initial start was made that would have led to the United States being technically competitive, we are now without technical experience to match the work by engineers and geologists in Finland and Sweden. Further, with the possible exception of France, other countries have not developed the necessary experience. Recent experiences by energy-dependent industrialized nations have now brought deep concern over the need not only to conserve oil consumption but also to store critical supplies of oil both for strategic as well as domestic use. The "Scandinavian experiences" are being sought to solve national needs by many nations, e.g., West Germany, Switzerland, South Africa, South Korea, Japan, and the United States.

12. At the present time, Finland and Sweden lead the world in experience in underground storage of oil in general and in the underground storage of residual or heavy fuel oil in particular. It is difficult to obtain a complete inventory of the completed, under-construction, and planned projects, but to give an example of stated accomplishments the following table has been abstracted from industry sources. In Finland, the Finncavern conglomerate of four companies are active in design and construction. In Sweden, two groups, SKANSKA and SWECO, appear as competitors. The only other company apparently that competes in the field is GEOSTOCK from France. (Other companies, described in Appendix A with literature in Appendix C, are active to varying degrees in different aspects of underground planning, design, and construction. However, they do not appear to be as dedicated to the

Underground Residual Fuel Oil Facilities

<u>Owner/Client</u>	<u>Completed</u>	<u>Volume m³</u>
<u>FINLAND</u>		
Neste Oy, Porvoo (U-12)	1971	199,000
City of Helsinki	1972	75,000
City of Helsinki	1972	75,000
Rauma-Repola, Oy	1972	280,000
Kotkan Hoyryvoima	1972	250,000
Imatran Voima Oy, Inkoo	1973	200,000
Imatran Voima Oy, Inkoo	1974	200,000
Finska Shell, Helsinki	1974	UK
Lahden Lampovoima Oy	1975	150,000
Neste Oy, Porvoo (U-18)	1976	211,000
Tahkoluodon Polttoöljy	1977	317,000
<u>SWEDEN</u>		
The OK Union, Stockholm	1960	UK
Svenska BP, Stockholm	1967	UK
Paktank AB, Sodertälje	1968	UK
Kema Nord AB, Stenungund	1968	UK
Rederi AB, Nordstjernan*	1968	115,000*
Karlshamnsverks Kraftgrupp*	1968	365,000*
Priipp-Byggerierna AB, Stockholm	1969	UK
Swedish Cellulose Pulp Co. Surdvall*	1969	80,000*
City of Vasteras	1971	UK
Sannes Gothenburg	1971	UK
Nynas Petroleum, Gothenburg	1972	UK
Handelo Oljelagringsförvaltning	1972	UK
Sodertorn Fjärrvarmeverk	1972	UK
The Stockholm Medical Services Adm.	1972	UK
The Stockholm Gas and Waterworks*	1972	90,000*
Svenska Cellulosa AB, Sundsvall	1972	UK
Tekniska verken i Linköping	1973	UK
The Swedish National Power Adm.	1973	UK
Krangede AB, Stockholm	1973	UK
Scanva't, Lysekil	1974	UK
The Port of Karlshamn	1974	UK
Handelo Oljelagringsförvaltning	1976	UK
Svarthalsfors AB, Stockholm	1976	UK
Norrbottnens Bergrumslagring	1976	UK
Modocell AB, Husum	1976	UK
The Port of Karlshamn*	1977	200,000*
Granges Ställ, Oxelosund*	1978	700,000*
Sundsvalls Energiwerk	1979	UK

* Taken from company brochures; in indicated cases, the term "fuel oil" was used and, therefore, not clear if residual oil or other forms of fuel oil are reported.

singular mission of promoting the use of underground space as the above-mentioned companies.) These companies are anxious to market their experience and cite contacts with the U.S. Department of Energy, Wesleyville (Ontario Hydro, Canada), South Korea, Switzerland, a proposal to the City of New Bedford, Connecticut, etc., as examples of their expanding marketing efforts.

Detailed descriptions

13. In the original plan for producing a generic study of the four storage media, it was decided to obtain data for four underground rock chambers and to assemble the information for each facility according to the following outline.

1. Present and Past Usage
2. Detailed Descriptions
 - a. Identification
 - (1) Name
 - (2) Location
 - (3) Size
 - (a) Facility
 - (b) Reservoir(s)
 - (4) History
 - (5) Product(s)
 - b. Engineering Study
 - (1) Agent
 - (2) Cost
 - (3) Site Description
 - (a) Area (Land Requirements)
 - (b) Geology
 - (c) Soil
 - (d) Groundwater
 - (e) Environment
 - (1) Land
 - (2) Water
 - (3) Air
 - (4) Time
 - (5) Special Features
 - (6) Problems
 - (7) Cost
 - c. Construction
 - (1) Agent
 - (2) Cost
 - (3) Time
 - (4) Special Features
 - (5) Problems

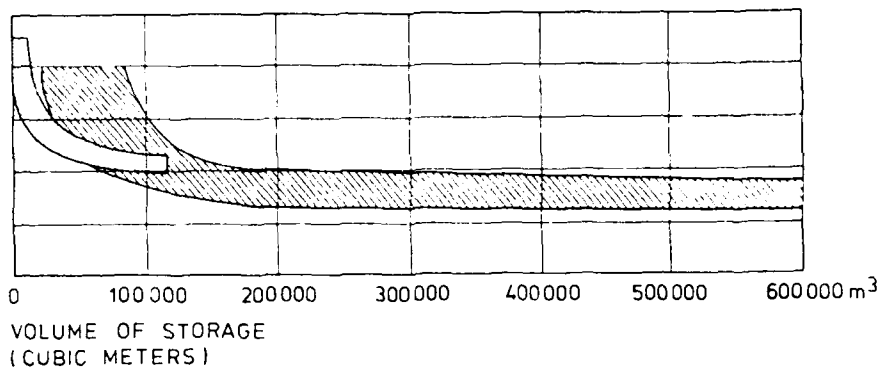
- d. Operation
 - (1) Filling
 - (2) Maintenance
 - (a) Temperature
 - (b) Gas Control
 - (c) Sediment Control
 - (d) Water Control
 - (e) Losses
 - (f) Repair
 - (g) Withdrawal
 - (3) Security
 - (4) Safety
 - (5) Cost
 - (a) Direct
 - (b) Indirect
 - (c) Life Cycle

Sufficient data were collected for two projects, the Tahkoluoto Underground Oil Storage Facility, Pori, and the Rauma-Repola Oy Facility, Rauma, both in Finland, to complete the outline of information. Literature collected for other cited projects may make it possible to complete the outline for several others. Time has not allowed such a compilation to be made for this report.

14. However, upon reviewing the planned outline, several general comments can be offered concerning the use of underground caverns to store residual fuel oil.

a. Because of their import status as well as the coincidence of peak usage periods and blocked harbors, Finland and Sweden must store crude oil as well as oil products.

b. By experience engineers in these two countries have found underground caverns to be the most economical. Opinions vary but, in general, underground storage becomes more economical when the volume of residual exceeds $70,000 \text{ m}^3$ (420,000 bbl). The following figure is widely disseminated. (No cost comparisons are available for use of abandoned mines or salt domes because each situation is extremely site-dependent. Buried concrete tanks, i.e., cut-and-cover storage, were categorically ruled out as not competitive.)



RELATIVE UNIT COSTS OF STORAGE FACILITIES

 UNDERGROUND ROCK CAVERNS
 SURFACE STEEL TANKS

c. A more direct comparison of estimated costs of a hypothetical storage of 250,000-m³ (1.6-million-bbl) facility is shown in the following table.

COMPARISON OF INVESTMENT UNIT COSTS BETWEEN ROCK STORAGE AND SURFACE TANKS (AN ESTIMATE)

Price level: Finland 1978

Product:

Heavy fuel oil

	ROCK STORAGE	SURFACE TANKS
DATA OF STORAGE		
SIZE OF STORAGE	1 600 000 bbl	8 x 200 000 bbl
LOADING CAPACITY	16 000 bbl/h	16 000 bbl/h
UNLOADING CAPACITY	2 500 bbl/h	2 500 bbl/h
STORING TEMPERATURE	+ 122 °F	+ 122 °F
INVESTMENT UNIT COSTS		
INVESTIGATION AND DESIGN	0,29 US\$/bbl	0,50 US\$/bbl
EXCAVATION	1,90 US\$/bbl	-
REINFORCING AND SEALING	0,26 US\$/bbl	-
STEEL TANKS (WITH INSULATION)	-	5,43 US\$/bbl
STRUCTURAL WORKS	0,35 US\$/bbl	0,74 US\$/bbl
EQUIPMENT AND PIPING	0,54 US\$/bbl	1,24 US\$/bbl
TOTAL	3,34 US\$/bbl	7,91 US\$/bbl

d. Analyses of direct construction costs of completed facilities are given the following range:

- Bedrock investigation	1 to 5 percent
- Planning and supervision	5 to 10 percent
- Excavation	45 to 65 percent
- Reinforcing and sealing	2 to 25 percent
- Structural works	6 to 16 percent
- Procurement and installation of equipment	10 to 30 percent

The actual cost of a completed $320,000\text{-m}^3$ (2-million-bbl) facility was given as:

- Research planning and supervision	\$ 525,000
- Blasting	3,500,000
- Reinforcement work	1,250,000
- Civil engineering	1,225,000
- Pipelines, pumps, and heat exchangers	1,000,000
- Electrification and instrumentation	<u>375,000</u>
	\$7,875,000

(Costs of land acquisition, interest, harbor development (and equipment), or filling pipes are not included. Also resale value of excavated rock is excluded.)

e. Besides the cited economic advantage of underground storage in relation to aboveground steel tanks, other obvious advantages include safety of operation, no fires (due to inadequate oxygen supply), limited danger of explosion (which can be designed for), low insurance premiums (if any), and virtually no impact on the surface or subsurface environment. In addition, the experience in construction shows that the facilities can easily be placed below existing tank farms, residences, or other structures without detrimental consequences.

f. The exceedingly good experience for Finnish or Swedish engineers results from sound, near-surface bedrock and a high groundwater table. Such conditions (and experience) make it relatively easy for geologists/engineers to choose an acceptable site. Furthermore, these conditions allow them to use large access tunnels (sloping 1:10 to 1:7) to accommodate efficient earth moving equipment and assure that

groundwater infiltration will be minimal. The relatively uniform soundness of the rock allows blasting design to be translated from site to site with the assurance that surface vibrations can be kept within acceptable limits. However, in planning for a new area, public acceptance may be different from that in Scandinavia. Accordingly, it may be advisable to construct a pilot project to gain public acceptance and, of equal importance, to obtain data to proceed with final design and construction strategy.

g. Design now appears to be going in two directions. Historically, underground oil storage facilities have been either a fluctuating water bed or a fixed water bed in principle. Residual oil storage facilities have always been a fixed water bed with direct heating of the oil and/or indirect heating of the water. More recent designs have been of a dry-bed principle with direct heating of the oil. In situations where groundwater infiltration is relatively excessive, it must be removed resulting in relatively excessive heat losses. In the dry-bed principle, the groundwater is caught in side sumps with a minimum heat loss. The savings in energy is partially offset by the cost of installing a concrete floor to the chamber, although such an installation is not necessary.

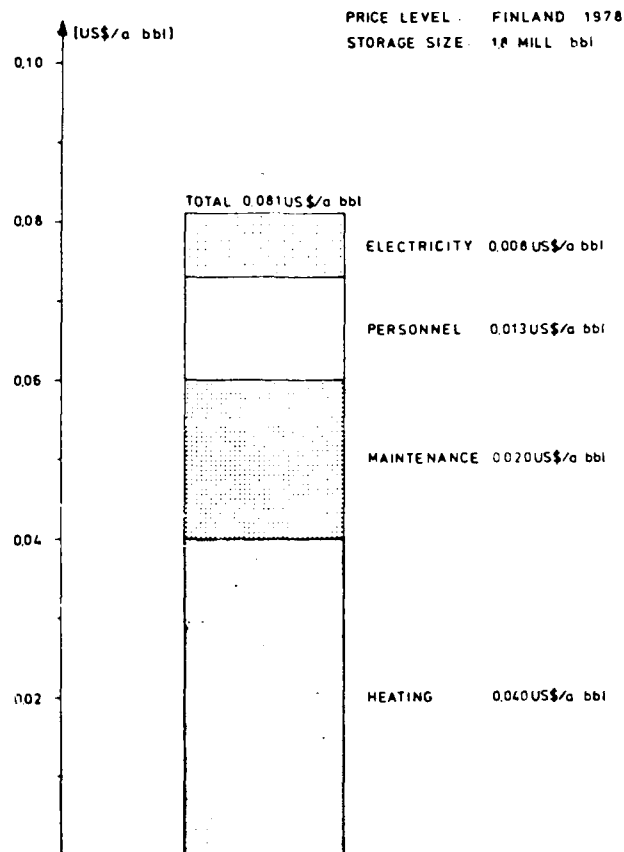
h. No experience is available for a sealed (or uncirculated) residual fuel oil reservoir. In all cases, the oil is cycled because of shared uses by residual oil fired power plants or transshipping operations. Opinions vary according to time, but no one expressed any doubts that residual fuel oil could be stored for several years (10-15) without any consequential effects. All pointed out that with a product such as No. 6 residual fuel oil that the economics were largely dependent upon a heat source such as a nearby power plant from which the energy wastes could be used to heat the oil.

i. No one had ever tried to store residual fuel oil without heating, although one company had conducted studies (with physical models) on ways and means of allowing the oil to congeal. One suggestion to allow long-term noncirculated storage was to substitute another grade of oil for No. 6. The suggestion stated that Russian No. 10 had much

the same properties as No. 6 but could cool to much lower temperatures without congealing.

j. Operational cost of course vary between large bounds. One estimate stated that the cost of maintaining a heating residual oil facility varied between \$75,000 and \$200,000/year or about \$0.02/ft³/year (energy, about 66 percent; wages, 24 percent; and repairs, 10 percent). Another source stated that the combined cost of operating and maintaining 19 underground caverns with a total volume of 4.3 million m³ (27 million bbl) of both heated and unheated oil to be \$0.05/bbl/year (\$0.007/ft³/year). The following figure shows in still another case, the cost to be \$0.081/bbl/year (\$0.014/ft³/year).

OPERATING COST OF HEAVY FUEL OIL ROCK STORAGE IN RAUMA



k. Operational problems centered mainly on two points: (1) excessive heat losses caused by excessive groundwater infiltration (a possible solution is the construction along the dry-bed principle); and (2) the buildup of slime along the oil/water interface (along with the resulting sludges) caused maintenance problems with the pumps and other equipment.

Conclusions and Recommendations

14. A two-week trip, discussions with numerous people, collection of a large amount of data--all with interruptions to attend to other business--and with virtually no time after the trip to reflect upon the collected data, information and impressions are certainly not conducive to producing an expert in the field. However, with those constraints, the following conclusions and recommendations are made:

a. It is strongly evident that the Finnish people (as well as the Swedes and French) are at ease with construction of underground residual oil storage facilities in hard rock. They have much less experience but, to varying degrees, demonstrated capabilities to construct facilities in lower quality rock. They are all anxious to export this knowledge and experience--especially to the U. S. in support of the SPR and RPR.

b. The people with whom I talked, in most cases, urged the construction of a pilot (or demonstration) project--much along the lines of the Japanese effort. Such a project would serve to increase public confidence but at the same time provide useful data for the design and construction of a completed facility.

c. Plans that call for noncycled (congealed) storage of residual fuel oil may not be economical or operationally feasible. The benefits of siting an oil storage facility in support of, for example, a residual oil-fired electrical generating plant with shared ownership of the oil may prove to be the optimum situation.

d. New technology is being developed (i.e., dry-bed

principle). Contacts with the leading proponents of underground residual oil storage should be maintained.

e. Underground storage of residual fuel oil in specially constructed chambers appears to be a safe, economical, and environmentally acceptable means of storage. Such a technique should be given every consideration when evaluating storage alternatives.

f. Given the national need, it is recommended that the generic study be completed as soon as possible to enable sound engineering judgments to be made on future engineering concepts for storage of residual fuel oil and to aid in selecting candidate areas for locating such facilities. It is further recommended that once the generic study is resumed that a representative or representatives of one or more of the leading companies be invited at U. S. Government expense to become a member of the study team and to share his experience so that the completed study will be as relevant as possible.

Appendix A: Daily Trip Report
(15-29 June 1980)

15 June; Helsinki, Finland

1. I was met by Mr. Stig Johansson, Engineering Geologist, Neste Oy. I was given a general tour of Helsinki, including a stop at Temppeliaukio Church (Photos 1-3). The church is set in a "bowl" blasted in solid rock. The walls are exposed rock surfaces. Rock from onsite quarrying was used to build the upper portion of the wall; inner and outer surfaces of the dome are of copper. I also had a windshield tour of the University of Helsinki area, Senate Square, Government Palace, Presidential Palace, Parliament House, and the Uspensky Cathedral. I was told that the owner of each building containing greater than 3,000 m³ must provide underground civil defense facilities (Class C); owners of larger buildings must provide additional underground space. The underground space can be used for storage, parking, and other multiple uses but must be capable of being cleared within 24 hr, upon notice, for civil defense use.

16 June; Helsinki, Finland

2. At the Ministry of Trade and Industry, I met with Mr. Johansson and the following:

Mr. Erkki Vaara, Director-in-Chief, Energy Department
Mr. Seppo Silvonen, Inspector
Mr. Kaj Kroktors, Engineer Economist

Mr. Vaara extended a hearty and open welcome to Finland with his wishes that information gained during my visit would prove to be beneficial to our study needs. He extended the hospitality of his department with the offer to be of any service possible during my stay in Finland. 1

Note 1: Photographs of items of interest discussed are shown in Appendix B.

Note 2: Bibliographic references are listed in Appendix C.

Note 3: Addresses of individuals mentioned (or otherwise contacted) are listed in alphabetical order in Appendix D.

responded by explaining the purpose of my visit. General comments by Mr. Vaara indicated that the personnel of the Energy Department of the Finnish Ministry of Trade and Industry and personnel of the US Department of Energy had held exploratory talks aimed at establishing bilateral agreements to exchange information; as Mr. Vaara indicated, those talks have not concluded. He expressed an opinion that, given the public opinion in the United States, consideration should be given to establishing pilot or demonstration projects for the Regional Petroleum Storage program--not to determine technical feasibility so much as to bolster public confidence. He indicated that crude oil and petroleum products are stored almost exclusively in Finland in underground hard rock caverns especially constructed for that purpose. Reasons cited included demonstrated economy, safety, and improved environmental surroundings. Mr. Vaara indicated that storage is in two categories:

a. State-owned storage. The contents are considered to be strategic to Finland's continued operation in case of an emergency. The caverns are sealed (noncycled) and have contained light fuel oils up to periods of 15 years without detrimental consequences to the fuel. No heavy oils have been stored in such a manner.

b. State-shared storage. Heavy fuel oils, for example, are shared with industry, such as power and transportation companies. Generally, the systems are cycled according to demands, but they think it would be possible to store the heavy fuel oils in excess of 10 years. Mr. Vaara mentioned that the heavy fuel oil is delivered from tankers at approximately 90°C and stored at approximately 50°C either by heating the oil or the water in a fixed bed system. In some cases, the contents can be heated by exchangers using heat wastes from the fueled power plants. He described pending legislation whereby power and industrial users may in the future be obliged to keep a certain portion of the shared oil reserves as strategic storage reservoirs. Users would, of course, be reimbursed for fulfilling that obligation. (Note: Sweden presently so obliges owners to keep a minimum amount for strategic purposes.)

3. Mr. Vaara stated that Finland was presently building the world's longest tunnel in rock (>120 km to provide Helsinki with new water

supplies). From that discussion, he emphasized the point that tunnels must go from one point to another and cross through the intervening geologic conditions in order to make the distance as short as possible. By contrast, underground storage sites may be chosen within broad bounds--both coastal or inland--at the most favorable sites. In fact, in his recollection only four sites, seriously considered after feasibility studies were completed, had ever been rejected. In these cases, faults, joints, and deep weathering were prominent geologic conditions leading to rejection. He indicated that, in general, underground storage becomes more economical than aboveground steel tanks when the required volume exceeds $70,000 \text{ m}^3$ (approximately 420,000 bbl). (Note: This breakover point varies slightly with individual opinions.)

4. Cut-and-cover techniques (buried concrete tanks) are not used in Finland because of noncompetitive costs, although a variation thereof was constructed (by Neste Oy) as the first state-owned facility near Inkoo. The feasibility of cut-and-cover techniques had been more recently investigated for use in a soft-ground construction situation in the Mideast but not recommended because of noncompetitive costs.

5. Mr. Kroktors offered some cost figures for operation and maintenance of underground storage caverns. In general, the consumer pays about 1 percent in addition to the purchase price to finance the operation and maintenance requirements. The total running cost at a given site varies according to the volume of stored oil, the site location with respect to user, and whether it is a state-shared or state-owned facility. For cold storage (i.e. at natural temperature of rock), costs may vary from \$30,000 to \$100,000/year. In this case, the cost is approximately $\$0.01/\text{ft}^3/\text{year}$ and is broken down as energy (electricity) approximately 16 percent; wages (and administration), 67 percent; and equipment repairs, 17 percent. For warm storage (i.e. heated), costs may vary from \$75,000 to \$200,000/year. In this case, the cost is approximately $\$0.02/\text{ft}^3/\text{year}$ and is broken down as energy at about 66 percent; wages, 24 percent; and repairs, 10 percent.

6. As far as safety is concerned, no explosions and only one fire have ever occurred in a crude oil storage facility. The fire extinguished

itself upon depletion of the oxygen supply; no cause was ever determined. The major problem is the cleaning of pumps at required intervals. (At times, a slime forms at the oil/water interface.) In Finland, conventional and nuclear power stations must have a seismic design (intensity on Richter scale of II to III), but not underground oil storage facilities.

7. Messrs. Silvonen and Kroktors indicated that the Energy Department has a design manual for underground sites as well as a maintenance, operation, and safety manual written specifically for each site. Manuals are written in Finnish, but perhaps examples could be obtained through official request and be translated into English as Official-Use-Only documents.

8. References not given but perhaps pertinent are (a) "Underground Oil Storage in Finland" by M. Kilpineu (Bibl: 1h) and (b) National Energy Data Report, Finland, 1979 (Bibl: 2).

9. Mr. Johansson and I met for lunch with Mr. Antero Hakapaa, Managing Director, Finncavern, Ltd., and Dr. Pekka Sarkka, Helsinki University of Technology.

10. During lunch at the Student Union Building, the conversation concerned general rock mechanic principles, studies, and interests. As a result of this conversation, the WES should send Dr. Sarkka the following publications:

a. Bieniawski's report on rock mass classification for use in tunnel design.

b. Cundall's and Voegele's reports on the discrete element methods. Further, because of Dr. Sarkka's interest in numerical methods, he will be interested to see the information contained in Chapter 9 of the report on rock mechanics limitation presently being published by the National Academy of Science.

11. Following lunch, a tour was made of the testing facilities at the Helsinki University of Technology, Department of Mining and Metallurgy. There I saw computer terminal facilities, rock test preparation machinery, dynamic test equipment, static test equipment, and a large "base-friction" modeling machine originally proposed by Goodman (Photo 4).

12. I received the following literature from Dr. Sarkka:

- a. Brochure of Helsinki University of Technology (Bibl: 3).
- b. Research Services of the Laboratory (Department of Mining and Metallurgy) (Bibl: 4).
- c. "The Finminers Group:" The Finminers Group offers mining machinery, equipment, and know-how from individual installations to complete turn-key package deliveries (Bibl: 5).
- d. "Sand Bunkers Blasted Out of Rock in Helsinki" by J. Polla and P. Sarkka, Rockstore 80, Stockholm 1980. Abstract: "The reasons to store sand in rock bunkers are described. A case history on the planning and excavation of the Malmi sand bunkers is presented. A complete state of stress measurement was carried out and the whole structure analyzed with a finite-element method. The results of these investigations verified assumptions based on previous experiences. The construction was carried out by means of long-hole drilling from above, simultaneously with tunneling from below" (Bibl: 6).
- e. "The Failure Behavior of Some Finnish Mine Rocks in Uniaxial Compression" by P. Sarkka, Thesis for the Degree of Doctor of Technology, Helsinki University of Technology, Helsinki, 1978 (Bibl: 7).

13. The data contained in paragraph 12d indicate that some $48,200 \text{ m}^3$ of sand bunker storage has been constructed in and around Helsinki from 1961 to the present. During that time, it appears that the average cost per cubic metre (including tunneling, concrete, ventilation, and reinforcement) has varied with time and location but averaged about $\$36/\text{m}^3$.

14. Later I met with Prof. Markku Tammirinne, Valtion Teknillinen Tutkimuskeskus (VTT), Geotekniikan Laboratorio and his assistants, Messrs. Hollopainen and Halonen.

15. The VTT (The Technical Research Center of Finland) is a nonprofit state research institution that conducts research and development in areas of:

- a. Building Technology and Community Development Division, consisting of 10 laboratories including the Geotechnical Laboratory where I visited.

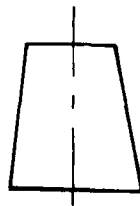
b. Materials and Processing Technology Division, consisting of 11 laboratories.

c. Electrical and Nuclear Technology Division, consisting of 8 laboratories.

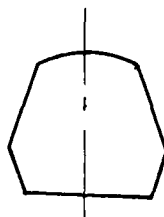
d. The Instrument Laboratory is located in the General Division. At the present, the VTT employs about 1,800 employees of which about 720 are professionals. The VTT receives allocated funding from the state government, which can be used to conduct generally applicable research and development studies, as well as reimbursable funding from other government and domestic and foreign firms (Bibl: 8 and 9).

16. Neste Oy had commissioned (on a reimbursable basis) a finite element study of three new chambers being constructed at the Skoeldvik Oil Refinery at Porvoo, hence the purpose of the visit.

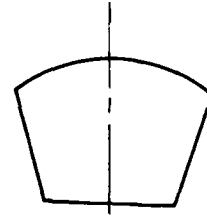
17. Mr. Halonen briefly discussed the results of a finite element analysis (linear-elastic, gravity turn-on, isotropic, and homogeneous material properties) of three cavern configurations in three states. In all analyses, a hydrostatic overburden pressure was assumed (1 mPa, I believe): in Case 1, the horizontal stress was equal to the overburden; in Case 2, the horizontal stress was equal to 5 MPa; and in Case 3, the horizontal stress was equal to 10 MPa. The three cavern configurations are shown below.



Configuration 1



Configuration 2



Configuration 3

(Not to scale)

The analyses were being conducted to help make design decisions for the construction of Chambers 20, 21, and 22 at Skoeldvik Oil Refinery. The results were not viewed as giving absolute values or predicting stresses or displacements on site but rather to give relative comparisons. Construction has been previously carried out in Configuration 1 on several occasions. Relative analysis of Configurations 2 and 3 showed

no reasons for additional concern over increased induced stress magnitudes or fields. Consultation with mining contractors, however, indicated that a shape such as Configuration 2 would be much more easily obtained with available equipment than with the other two shapes--thereby resulting in considerable savings. A preliminary decision had been reached to construct the new caverns in the shape illustrated by Configuration 2.

18. Mr. Hollopainen showed laboratory rock test facilities including a uniaxial failure of a rock core with complete stress-strain monitoring. (The Finnish typically use 32-mm cores because of the uniformity of the granite and other Precambrian rock.) Data reduction equipment and a cold storage test facility was reviewed.

19. Upon the return trip into the city of Helsinki, I "saw" the first of several underground residual oil storage facilities (Photo 5). Mr. Johansson was proud of the fact that no disruption to a pleasing and environmentally acceptable area could be seen in spite of the fact that several million barrels of fuel were stored underground to fire the nearby electrical generating plant. The only surface expression was the small control building (Photo 6).

20. I later met with Mr. Hakapaa; Prof. Raimo Matikainen, Helsinki University of Technology; and Mr. Pekka Lappalainen, Project Engineer, Outokumpu Oy Mines. Discussions were general in nature. Important items centered on work and activities at the WES and by the U.S. National Committee on Rock Mechanics, in particular on the in situ stress measurements and the discrete element method of analysis. We should send:

- a. Cundall's and Voegele's reports on the discrete element method to Mr. Hakapaa.
- b. Summary of WES Capabilities to Mr. Hakapaa.
- c. Reports on in situ stress measurements (Dames and Moore; de la Cruz; and NAS study, Chapter 4) to Mr. Lappalainen.
- d. The entire NAS study to Prof. Matikainen.

17 June; Pori, Rauma, Raisio, Turku, Finland

21. Mr. Johansson accompanied me on a visit to the Tahkoluoto

underground oil storage facility at Pori (Photo 7; Bibl: 10). The town is located about 225 km west of Helsinki on the Baltic Sea. The underground oil storage facility pumps heavy fuel oil from the ocean terminal about 500 m distant into three chambers of a total volume of about 1.8 million bbl (Photo 8). The facility is shared with a portion of the oil being held in reserve for national strategic demands and the remainder for use in a nearby power plant and for transshipment via truck to other plants (Bibl: 11).

22. The storage operates on the dry-bed principle. The three chambers (each 16 m wide, 29.8 m high, and 222 m long) have a concrete floor with longitudinal sumps to collect the groundwater seepage. At present, the seepage quantity is about $26 \text{ m}^3/\text{day}$ at a temperature of about 37°C . The only other dry-bed facility recalled by Mr. Johansson was located at Lahti--again used for heavy fuel oil. (Note: Future discussion with Mr. Saarni (Ekono) indicated that both the oil storage facility at the Mussalo condensing power plant operated by Kotkan Hovryvoima Oy and Sunita Oy, as well as the one at Vaasa, was possibly designed on the dry-bed principle.) The oil is continually circulated and returned at various points at a temperature varying from 55° to 58°C . The oil is heated to about 62°C for transshipment by motor tankers. (It was estimated that the temperature would drop about 2°C for a 180-km trip.) At the time, six ports for motor tankers were provided (Photo 7). Government regulation requires that the underground storage facility be equipped with rail tanker loading and unloading facilities (at present nonexistent). Further, government regulations require that, before a permit is issued, the site conditions, configuration, and engineering design be such that the capacity of a plant can be doubled over a Phase I permit. At Tahkoluoto, no immediate plans exist for expansion.

23. The facility is owned and operated by Tahkoluodon Polttoöljy Oy, which was described as a "paper company." The term means the "company" was founded by other companies to principally operate as a fuel reserve for the nearby power plant but to gain income from the shared ownership by the state for strategic supplies and from independent sales. The operation is unbelievably simple. The Managing Director, Mr. Haavitesto,

was not present, but in his absence, Mr. Nurmii, Operations Manager, and a bookkeeper were the only personnel required for continued operation. Each driver had to pass a course dealing with safety and operation of his vehicle while on the premises. He then was given a key, which allows 24-hr access for loading. His company affiliation, the volume of fuel oil received, etc., were automatically recorded for future billing. Mr. Nurmii and the bookkeeper worked from 0700 to 1600 daily. During that time they carried out routine maintenance, checked all system components, and recorded billings (Photo 9). At other times, control of the operation was shifted to the control room of the power plant to be monitored by personnel located there. Should a malfunction occur, Mr. Nurmii was notified by phone, appraised of the nature of the malfunction, and depending on the severity of the situation, either returned to the site (if an emergency) or described the corrective remote action to the power plant personnel (if a nonemergency). Mr. Nurmii indicated his most important concerns were (a) an oil spillage in the sea, (b) a broken pipeline to facility, (c) a fire somewhere in the system, (d) a broken unloading arm, and (e) an overturned truck on premise.

24. The facility was constructed by Oy Yleinen Insinööri-toimisto (Y.I.T.) in an olivine-diabase material. Importantly, the facility was planned as an integral part of the power plant since the spoil material was used as breakwaters and construction dikes to allow oil and coal ships to dock, unload, and store cargoes safely. Significantly, site selection was not aided by rock outcrops (one occurs with an area of approximately $40\text{-}60\text{ m}^2$). The siting was done by general engineering geologic knowledge of rock conditions in Finland, a knowledge of the more specific conditions in the area, a few seismic profile lines, a few verifying borings, and observations of water levels in the borings and general water levels in nearby depressions.

25. Our tour included a view and explanation of the control room (Photo 9), a descent of the access (pump) shaft, a view and explanation of the equipment cavern (Photo 10), a view and explanation of the skimming/ separating of pumped water (Photo 11), the oil cavern plug and water barrier, and a walk up the access tunnel (Photo 12).

26. My general observations were that the plant was well sited, well operated, and demonstrated the possibility of choosing a site for an oil storage facility that can operate in a safe, efficient, and at the same time, environmentally acceptable manner. Further observations were that the design was acceptable since the rock mass required only occasional strengthening by rock bolts/shotcrete; seepages were few (although the access tunnel seemed to contain air with a high humidity content).

Impressive was the fact that construction was carried out beneath existing oil storage tanks (Photo 13) by controlling the particle velocity to 50 mm/sec with an occasional maximum value of 75 mm/sec.

27. Mr. Johansson and I met with Mr. Sararanta, Cavern Foreman, at Rauma-Repola Oy, located in Rauma (Photo 14; Bibl: 12). (Mr. Makela, Cavern Operator, was not present.) Rauma-Repola Oy is the largest private industrial company in Finland with over 16,000 employees and annual sales of over \$700 million. The company operates manufacturing plants, shipyards, sawmills, plywood factories, (prefab) house factories, a paper mill, a pulp mill, and a quarry. Rauma is located on the Baltic Sea about 240 m from Helsinki. The fuel oil facility consists of two parallel caverns, 16 m wide, 29 m high, and 300 m long, for a total storage volume of $280,000 \text{ m}^3$ (approximately 1.7 million bbl). The heavy fuel oil stored at the Rauma-Repola Oy facility is share held (about 74 percent for Department of Energy for strategic use; 16 percent standby usage for the Rauma-Repola power plant; and 10 percent for the power plant operation at the nearby city of Tampere). The Rauma-Repola power plant is dually fired by coal and oil. At the present time, the plant is using coal with only a small quantity of oil being used in the plant. Heat wastes from the plant are used, however, to keep the oil heated (around 51°C in summer, and 55°C in winter). The heating operation includes both indirect heating (of water) and direct heating of oil. The caverns operate with a 1-m-deep fixed water bed. At the present time about 75 m^3 of seepage water must be removed daily at an average temperature of about 40°C . Removal is accommodated by using one $15 \text{ m}^3/\text{hr}$ capacity pump for about 5 hr daily. (Regulations require that all caverns, as at the Rauma-Repola facility, have duplicate capacity water

pumps.) The access tunnel is separated from the equipment room by doors, again by regulation, designed to withstand 20 atmospheres internal pressure and 10 atmospheres external pressure.

28. The access tunnel area serves dually as a defense shelter for a portion (about 350) of the work force at Rauma-Repola (Photo 15). It was stated that oil did have a lingering odor; therefore, the water removed from the caverns was pumped to a surface skimming facility before being passed to the water purifying plant. Treatment of the water was stated to be such that the oil content of the water was 10 times less than required for drinking purposes (as compared with a required 1 ppm content of oil). During the winter, the skimming facility is heated by direct wastes from the plant.

29. The bedrock is granite gneiss of good quality. After 7 years, only a few spalls (estimated to be less than 0.5 m^3) had occurred (Photo 16). Equally impressive was the fact that the visited cavern and another nearby facility were constructed under existing facilities (a restaurant and houses) without damage (Photos 17 and 18).

30. We later stopped at a location known (in English) as Red Hill to look at an underground sewage treatment plant (Photo 19). No one was at the plant, so we proceeded to another underground sewage treatment plant at Raisio, a city of about 17,500 people located on the Baltic (south-west Finland) (Bibl: 13). The electrical engineer and foreman onsite met us. In addition to treatment of city wastes, a margarine plant was also supplying waste water for treatment. At present, treatment facilities are located in two chambers with a combined treatment capacity of about $12,000 \text{ m}^3/\text{day}$ of waste water (Photo 20). Presently the plant is treating about $11,000 \text{ m}^3/\text{day}$. To accommodate anticipated growth and needs of the area, a third chamber ($18 \times 18 \times 139 \text{ m}$) had been excavated parallel with and separated from the older caverns by about 14 m. Apparently, the excavation had not caused any problems since it was handled in the "routine precautionary manner."

31. The power requirements are listed as 600,000 Fmk/year; water, 240,000 Fmk/year; and chemicals, 200,000 Fmk/year. These costs, plus salaries and other expenses for operation and maintenance, brings the

total cost to 3,500,000 Fmk/year (approximately \$1,000,000). The margarine factory pays in proportion to its use (about 60 percent); the people pay the remaining portion (about 40 percent). The latter figure is arrived at by a flat fee of 2 Fmk/m³ of water used (1 Fmk/m³ for purchase of the water and 1 Fmk/m³ for treatment).

32. The information obtained at the Raisio treatment plant has nothing to do with underground storage of oil but indicates another use the Finns have unhesitatingly made of the underground.

33. A similar observation was made at two stops in Turku, a town in the same locale as Pori, Rauma, and Raisio. Here we first visited the Myllyahde Traffic Tunnel and an underground civil defense shelter that will serve (again subject to 24-hr notice) as an ice hockey rink for training purposes. At the Myllyahde Traffic Tunnel (Photo 21), the rock is supported by 124 bolts and a shotcrete lining. A tunnel, at a skewed axis to the traffic tunnel, leads to an underground facility for the transformer station for the city. Two things are of interest. During construction about 15 m³ of material fell out of the crown of the tunnel portion (Photo 22). For aesthetic purposes, the rock was fitted back to restore the natural appearance of the surrounding rock. Secondly, efforts were performed to make the lower, blasted surface of the rock to the right of the tunnel entrance match the appearance of the higher, natural outcrop (Photo 23).

34. We then met with Mr. Siren, Project Manager, and Mr. Raty, Field Manager for Oy Yleinen Insinööri-toimisto (Y.I.T.), the company responsible for the civil defense shelter. We walked down the access tunnel to where two caverns were being constructed. The final cross-sectional dimensions are to be 32 m wide and 18 m high in a half-circle shape. This cavern, according to Mr. Johansson, will have the largest cross-sectional area in Finland. The facility will provide shelter for about 11,000 inhabitants of nearby apartment houses (Photo 24). Material being excavated is hauled to a plant to be crushed for later use by the city of Turku as aggregate for roadway surfaces. The noncritical use of the facility as an ice skating rink again illustrates the innovated use of the underground.

18 June; Helsinki and Porvoo, Finland

35. At Ekono Oy, I met with Mr. Johansson and Mr. Tuomo Saarni, Manager, Marketing Energy Sector (Bibl: 14, 15, and 16).

36. Ekono Oy is one of the four companies forming the Finncavern group. It is an engineering consulting company specializing in power and heat generation, industrial engineering, regional technical planning, and environmental protection. It has an office in Bellevue, Washington, and has conducted several studies in the United States--mainly in connection with paper mill operations. In cavern projects, Ekono has concentrated on engineering and supervisory services. The Tahkoluoto Oil Storage Plant Project, paragraphs 21-26, is one example (Bibl: 15). The offices are housed in the Ekono House (Bibl: 16). The building has 137,000 ft² (12,790 m³) and contains energy-efficient features including a computer control system and bedrock storage of solar energy. To give an indication of the engineered efficiency, office buildings in the United States average 290 kwhr/m², whereas the Ekono House uses 70 kwhr/m² in total annual heat consumption. The total annual electricity consumption for office buildings in the United States is 190 kwhr/m² and for the Ekono House it is 57 kwhr/m².

37. Mr. Saarni indicated that the construction of the Tahkoluoto Oil Storage Plant was basically justified as being part of a power complex but that sharing of the waste rock (for breakwaters and area for coal storage and storage for oil consumers) played an important part of the decision to build. The dry-bed principle at Tahkoluoto is similar in operation to the fixed-bed principle. The dry-bed principle is favored because oil and water do mix slightly at the contact. With the dry-bed operation, the contact area, as well as the indirect heating of the water, is eliminated. Cost reduction of the dry-bed operation is offset by increased cost associated with the installation of a concrete bottom in the cavern. Mr. Saarni knows of two other such installations, one at Kotkan and the other at Vaasa.

38. Mr. Johansson and I met at the Skoeldvik Oil Refinery (Neste Oy) in Porvoo with Mr. Yrjo Ignatius, who is both Assistant Director of Neste Oy and Chairman of the Board of Finncavern; Mr. Esko Koskineu, Chief

Design Engineer, Neste Oy; and Mr. Matti Oksanen, Manager, Technical Export, Neste Oy. We later were joined by Mr. Jose Cardenas, Neste Oy's Mexican representative. Neste Oy (Bibl: 17 and 18) is the national oil company of Finland and is one of the four members of Finncavern (Bibl: 19). The company operates the only oil refinery in Finland and uses both surface tanks and underground storage caverns to hold both crude oil and refined products. At the present, some 4.3 million m³ (approximately 26 million bbl) of underground storage is available with three new chambers under construction (see paragraph 16). Residual fuel oil is stored in two caverns with a combined volume of 409,000 m³ (approximately 2.4 million bbl). In all cases, the caverns at Neste Oy operate on the fixed water-bed principle.

39. While at the refinery, we viewed the surface features of the U-16 cavern, which is a crude oil facility (Photos 25 and 26), a dry well pump room (Photo 27), and construction activities associated with the new chambers U-20, 21, and 22 (Photos 28 and 29).

40. Mr. Ignatius has consulted with the DOE on siting requirements for the Strategic Petroleum Reserve within the United States. He reports that several sites along the east coast of the United States are suited for underground storage. But he is pragmatic about the situations that lead to decisions to go underground with either crude or refined products. In the United States, he says, in the past there had not been any economy associated with storage--especially since the United States has been a major producer and even an exporter; whereas Finland not only must import all their oil but at the same time must face a winter season in which all ports are frozen in. Thus, in all, Finland must store for strategic purposes (both crude and refined), for commercial consumption, and to balance production flow. In Finland, the present underground storage capacity is about 10 million m³ (60 million bbl).

41. Residual fuel oils are normally of two main grades, 230 or 650 centistokes at 50°C. The cost of maintaining an underground storage is much lower than aboveground insulated steel tanks. However, precautions must be made to ensure small water flows since removal of the water is a main reason of heat losses. Actual operation and maintenance

costs comparisons between steel tanks and underground storage are difficult to make since the size of the operation varies so greatly. However, at Skoeldvik Oil Refinery about 100 steel tanks are operated and maintained at a cost of about \$0.30/bbl/year; the 19 underground chambers are operated and maintained at a cost of about \$0.05/bbl/year. The maintenance of equipment is generally more complicated in underground chambers than aboveground tanks. As a result of possible corrosion but difficulty in replacement and repairs, critical components are generally designed for a 20- to 50-year operation. There was the mention of possible formation of sludges in the bottom of the caverns. In principle, the formation causes no problems to the continued operation, but periodic cleaning of pumps, etc., are required.

42. Problems with groundwater inflows were discussed. The inflow ensures that groundwater contamination will not occur. However, only nominal amounts of inflow are desired since the water must be removed by pumping to ensure proper operation of the underground oil storage facility. In the case of a residual oil storage facility, the inflow causes an additional concern in that the additional groundwater is the source of a heat loss. Flows ranging from 1 to 20 m³/day/100,000 m³ were cited as being tolerable at the Skoeldvik Oil Refinery.

43. Mr. Ignatius emphasized proper maintenance of level and alarm systems (with redundant measuring capability) to guard against over filling. He said pumping systems can fail and not pose a serious immediate threat to the facility because generally the design is so conceived. Fires cannot occur in the caverns because of insufficient oxygen supply. He did say that explosions are possible at times with a critical mixture of gas fumes and air.

44. As an additional reason to consider underground caverns (other than safety, lower costs, and a more environmentally acceptable solution), Mr. Ignatius cited the low insurance costs associated with the product.

19 June; Outokumpu

45. Mr. Hakapaa and I met Mr. Risto Heiskanen, Chief Mining Engineer of Outokumpu Oy. Outokumpu Oy is Finland's largest mining and metallurgical company. The visit included a trip to the Keretti mine near the

town of Outokumpu and the Vuonos mine about 4 miles from town. The principle product of these two mines is copper. We viewed the crushing operations and general layout of the ore handling operations (Bibl: 20, 21, and 22).

20 June; Outokumpu

46. Discussions continued with Mr. Hakapaa concerning directions possible under the Regional Petroleum Reserve study, if and when it should be resumed. In addition to data exchanges, I was particularly interested to learn that Finncavern might be willing to consider a loan of personnel for short periods of time.

47. While out of sequence, to make this portion complete with respect to Finnish contacts, I met Mr. Touko Allonen, Vice-President of Vesto Oy, who is also a member of the Finncavern Group. Vesto Oy is a construction firm. Also I met Mr. Raimo Vuolio of Finnrock, AB.

48. Bibliographic items 23-33 are of direct interest.

21 June; Helsinki, Finland, to Stockholm, Sweden

49. Mr. Robert Bangert, Executive Secretary to the U.S. National Committee on Rock Mechanics (USNC/RM), and I met to go over items on the agenda for the International Society for Rock Mechanics (ISRM) Council Meeting for 22 June 1980.

22 June; Stockholm, Sweden

50. The Council Meeting of the ISRM was called to order by the President, Prof. Walter Wittke, West Germany. Role was called and a quorum established by Dr. Arnaldo Silverio, LNEC, Portugal. Minutes of the Montreux, Switzerland, meeting (September 1979) were presented and adopted upon motion by the United States (Banks); seconded by the United Kingdom (Brown); and there was no objecting vote.

51. The written report of ISRM activities was reviewed by Dr. Silverio with verbal expansion on several items.

a. Bulgaria, Iraq, Korea, Albania, Saudi Arabia, Rumania, and a number of African countries have been contacted to encourage membership in the ISRM.

b. By letter dated 15 May 1980, Japan paid dues for 162 individual members and 62 supporting members, thus becoming by far the nation

making the largest payment to the ISRM; this payment has significantly increased the financial well-being of the ISRM.

c. Poland is no longer a member of the ISRM because of nonpayment of dues. The national group purportedly was highly oriented to mining activities and, therefore, reported receiving adequate representation through the International Bureau of Rock Mechanics.

d. In the past, Chile has had two groups: one officially recognized by the ISRM but inactive; the second not recognized but active in technical matters. The Vice-President for South America had been asked in the past to clarify the situation. It was announced that the two groups have merged and paid dues and that Chile is now a member nation in good standing.

e. Continued and increased help was requested in obtaining bibliographic material to be used in the ISRM Newsletter. (Note: I suggest that the USNC/RM consider making the Secretariat a clearing house for reports, annotated bibliography, or an annual bibliography of rock mechanics studies in the United States to satisfy this request.)

52. The activities report was approved and adopted upon motion by Brazil (Kanji); seconded by Switzerland (Kovari); and there was no objecting vote.

53. Dr. Silverio reviewed the financial situation for the ISRM. Again the Japanese contribution of \$4,343 was noted. Dr. Silverio commented that \$44,000 was in a fixed savings account bearing 17 percent annual interest, and he expressed amazement, but pleasure, at the large amount of income being realized through the purchase of ISRM publications. While pointing out that he thought publication and distribution of ISRM materials by Pergamon Press should have been sufficient to largely meet the needs of the rock mechanics community, a six-fold increase in purchased material had occurred to indicate a growth of worldwide interest in rock mechanics.

54. The financial report was approved and adopted upon motion by France (Duffaut); seconded by Brazil (Kanji); and there was no objecting vote.

55. Dr. Silverio reviewed the budget for 1981 and indicated that Account #11 (for publication) was largely hypothetical since receipts

were impossible to estimate and disbursements were even more difficult to determine. Accordingly, the estimated receipts are divided, two-thirds to publication and one-third to the balance. The budget is so prepared to indicate a capacity rather than an intent to publish reports. The budget report was approved and adopted upon motion by the United Kingdom (Brown); seconded by Italy (Motta); and there was no objecting vote.

Kanji (Brazil) noted his appreciation of the growth of the ISRM fixed account but suggested that the Board start thinking of ways in which the excess funds can be used to further the growth of the ISRM. Kanji requested the Board establish an early policy. Wittke responded that the Board had been having conversations along establishing such a policy.

56. Reports of ISRM Commissions were given by the chairmen, if present, and by Dr. Silverio if the chairmen had sent their reports. Wittke reminded delegates of the extremely short time between his election (September 1979) and the present. That short time has meant that new commissions are still in the formative stages, old commissions have been terminated (by statute) but continued (by executive order) where work remains to be done, and needed new commissions are being established. The new commissions are particularly important since the ISRM has agreed to emphasize mining activities to a greater extent than in the past. Wittke further requested more active interest and initiative be evidenced by the national groups by providing the names of individuals who would be qualified to serve on each commission. (Note: I recommend that such a list from the United States be prepared and forwarded to Prof. Wittke. On commissions in which the United States presently holds membership, that fact, along with their names, should be so noted without necessarily naming new prospective members.)

a. Commission on Case Histories. As Chairman, I gave the following report:

Report of Commission on Case Histories

Don C. Banks, U.S.

Stockholm, 22 June 1980

At the last Council meeting of the International Society for Rock

Mechanics (Montreux, September 1979), a proposal to establish a Commission on Case Histories was made by the National Group of the United States. The proposal was accepted by the Council. The purpose of the Commission is to assemble case histories to gain insight into justification and procedures for various site investigation, design, and construction approaches involving rock media. It is anticipated that lessons learned from case histories can clearly lead to more economical and safer rock mechanics design practice--whether it be from an educational or informational standpoint.

On 3 December 1979, the President invited Dr. Don Banks to become Chairman of the Commission and, if accepting, to submit a list of potential members. After discussion with the National Group of the United States, acceptance, and a submittal of the names of potential members was made by letter to the President, ISRM, on 21 February 1980. A total of eight names was submitted. On 28 April 1980, the President sent letters to the eight people asking for their agreement to serve on the Commission.

<u>Name</u>	<u>Country</u>	<u>Interest</u>	<u>Accepted</u>
Horace Wagner	South Africa (Africa)	Mining	
Shunzo Okamoto	Japan (Asia)	Civil	X
Lance Endersbee	Australia (Australasia)	Civil	
Alberto Motto	Italy (Europe)	Civil	X
Pierre Londe	France (Europe)	Civil	
Don Coates	Canada (North America)	Mining*	
Z. T. Bieniawski	United States (North America)	Mining	X
Dinnis da Gama	Brazil (South America)	Mining	X

* Personally declined but suggested D. G. F. Hedley, Canada (North America), Mining, who accepted.

Thus, a quorum has accepted the invitation to serve on the Commission. Our next step will be to complete the Commission membership concurrent with invited selected individuals to work with the Commission in establishing model case histories to be used as a guide for individuals who propose future case histories.

Evidently the Commission is still in the formative stages but

hopefully at least two case histories will be prepared within the next 12 months.

b. Commission on Computer Programs. A written report by Stephen Semprich was read. The Commission will emphasize application of computer programs to underground openings. (Note: Chapter 9 of NAS report may be of interest to this Commission.)

c. Commission on Research. A representative from Sweden will chair this new Commission; plans have not been clearly established. (Note: Entire NAS report may be of interest to this Commission.)

d. Commission on Falling Rocks. In the past, this group was called Commission on Dynamics of Rock Falls and Protection against Falls. The present thinking is that while the old Commission was terminated with Fumigalli resigning, much interest remains, particularly in France, Switzerland, and the United States. The National Group of France (Maury) will make the formal proposal in 1981 (in Tokyo); in the meantime, ideas on operation, information available, etc., are being solicited. (Note: Once a name has been submitted from the United States as a prospective member that person should be requested to submit ideas, although his ultimate appointment to the Commission may or may not occur.)

e. Commission on Swelling Rocks. The Chairman, Bill Bamford (Australia), has been invited to continue the Commission and to serve as Chairman. His report centered on five areas of activities: (1) Characteristic of Swelling Rock; (2) Classification of Swelling Rock; (3) Identification of Problem Areas; (4) Analysis and Design of Engineering Structures; and (5) Laboratory and Field Testing (with coordination with Commission on Testing Methods). Mr. Bamford indicated that he intended to have a working document of the Commission's study available for the Tokyo meeting in 1981.

f. Commission on Teaching. The Chairman, Dr. Ed Cording, reported that a first draft of the report compiled from the Commission questionnaire was being reviewed with the intent to complete by the Tokyo meeting. Some figures and statistics were given. At present, it appears that the teaching of rock mechanics and employment of rock mechanists are shared about equally (40/40) between civil engineering and mining engineering

with the remaining 20 percent in engineering geology and other fields. In the survey, 104 universities reported--52 with a Ph.D. program and 26 with an "extensive" program. (Note: The Commission should be appraised of and kept aware of the USNC/RM intention to hold a workshop on "Rock Mechanics Teaching Requirements" at Berkeley, California, in 1982.)

g. Commission on Testing Methods. Prof. E. T. Brown, who has been working closely with the Commission Cochairmen, Franklin and Bieniawski, reported. Prof. Brown will edit a book on testing techniques to be published by Pergamon Press. The book will be in English but may be translated later into other languages at Pergamon's risk and expense. Of the 15 test methods to be published, 10 have previously been published in Pergamon journals; 2 are scheduled for publication in Pergamon journals; 1 has been published by Springer-Verlag; and 2 are newly developed. In the agreement, all sales by Pergamon will result in the ISRM receiving 10 percent; special consignment orders of bulk quantities can be ordered for sale by the ISRM of which 40 percent remain with the ISRM.

h. New Commissions were announced as follows:

(1) Excavation of Rock to be chaired by Prof. E. T. Brown (Imperial College) and to emphasize the ability of rock to be bored, cut, and drilled.

(2) Design of High Rock Slopes. Don Coates and Doug Piteau (Canada) have been asked to serve as Cochairmen.

(3) Dilation of Rock. Prof. Lombardi has been asked to serve as Chairman.

(4) Erodibility of Rock. Chairman is still open. A request for ideas was made. (Note: Dr. Ed Perry (WES) may have some ideas.)

(5) Geothermal Energy. Prof. Diakin (USSR) has been asked to be Chairman of the Commission.

(6) Tunneling Failure and Remedial Measures. The Chairman will be Dr. Manual Rocha (Portugal). The new Commission replaces an older one (Tunneling), which was dropped because of inactivity. (Note: The Chairman of the Case History Commission was asked to name a liaison member. Dr. Z. T. Bieniawski was nominated.)

57. Kanji (Brazil) stated that he wanted to launch the idea of a future

Commission on Dynamic Properties to include studies of natural and artificial induced earthquakes, vibrations from foundations, blasting, and large explosions, and possibly tectonophysics. He stated his belief that such a commission would require assistance from other commissions, specifically mentioning work from the Commission on Computer Programs. Upon questioning from the Chairman, Kanji stated that his suggestion was not a proposal, merely a suggestion, and that if Brazil chose to make a formal proposal in Tokyo, he might not be in a position to handle the chairmanship.

58. The China National Group sent a letter suggesting a special study of Rheological and Long-Term Strength Behavior of Jointed Rock. This suggestion was put in the same category as Kanji's suggestion.

59. Kovari (Switzerland) commented that initially commissions had simply defined aims and scopes, but now commissions are studying problems where no data exist, citing Commissions on Failure of Tunnel Openings and Swelling Rock. Such commissions, he stated, exist without clearly defined aims and scopes; he suggests why some commissions succeed and some fail. Wittke defended by stating that the cited commissions were sanctioned by previous ISRM councils and that useful work can come from commissions where problem definitions can be the ultimate aim.

60. Motta (Italy) suggested that commission membership be a result of the President's solicitation to national groups rather than to individuals. Wittke responded that the suggestion has to a large part been implemented by his previous request that national groups present names to him for nomination to the individual commissions. Bamford (Australia) indicated that the discussion of the Board has suggested that the names of individuals identified to serve on boards by national groups be passed through the respective vice-presidents, then to the president (and secretariat), and from the president to the commission chairman.

61. The Permanent Coordinating Secretaries (PCS) of the ISRM/ISSMFE/IAEG met in Brussels during the week of 7 June for discussions. Items considered were:

- a. Difficulty of obtaining members from Africa, Mideast, and Far-East.

- b. Conflict (and coordination) of meetings.
 - c. Uniformity or standardization of format, style, and method of printing of papers.
 - d. Activities of the PCS: (1) Literature Classification; (2) Symbols, Units, and Definitions (in eight languages); and (3) Site Investigation and Sampling.
62. The International Bureau of Rock Mechanics' representative reported no meeting since Montreux in September 1979, and therefore, nothing new to report. The next meeting will be in June 1981 in Poland. The representative expressed appreciation that the 5th Congress on Rock Mechanics will emphasize mining applications of rock mechanics.
63. The International Tunneling Association's (ITA) president called for closer cooperation between ITA and the ISRM. (The ensuing interchange indicated that close cooperation should not be difficult since he and the ISRM president both resided in Aachen, FDG.) He indicated that the ITA did not accept individual membership but was composed of members from 26 nations. The ITA has nine working groups (i.e., commissions):
- a. Subsurface Planning
 - b. Contractor Sharing of Risks
 - c. Structural Design Models
 - d. Safety in Works
 - e. Maintenance and Repair of Underground Works
 - f. Seismic Effects on Underground Structures
 - g. Standardization (Glossary on Tunneling Machines and Explosives)
 - h. Catalog of Works in Progress
 - i. Research
64. The president of ITA stated that the aims of the ITA working groups were different from the aims of ISRM commissions but several were closely parallel. He, therefore, suggested close coordination.
65. The International Society for Soil Mechanics and Foundation Engineering (ISSMFE) representative stated that their organization was the oldest and most populated (20,000 members in 50 countries) of all the geotechnical societies. He indicated that their work is done by commissions that in some aspects were parallel to those of the ISRM. He

discussed the upcoming Tenth International Conference to be held in Stockholm in 1981.

66. The Conference on Structural Foundations on Rock was discussed by Bamford. About 150 attended with 50 being mainly from Australia, Britain, Canada, New Zealand, and the United States. He mentioned discussions of the design of piles on rock and tunnel design and construction.

67. The Australian/New Zealand Geomechanics Conference was discussed by Bamford; about 200 attended. He described the interdisciplinary aspects of the conference in that soil and rock mechanics and engineering geology were discussed. He especially mentioned subjects dealing with rock cutting and rock breakage. At the conference, the John Jaeger Memorial Award for excellence in the field of geomechanics was given for the first time to Prof. Ted Davis. (Note: Private discussions later indicated that this was to be a repeating award, but consideration at the present was only being given to workers in Australia and New Zealand.)

68. A description of ROCKSTORE 80 plans and activities were given.

69. The International Symposium on Weak Rocks to be held in Tokyo on 21-24 September 1981 was described by the Japanese delegate. A bulletin was distributed.

70. Tunnel 81, to be held 11-13 June 1981 in Dusseldorf, Germany, was announced. The meeting will be in connection with the International Mining Congress, but the bulletin has not yet been finalized for printing. The purpose will be to discuss areas of common interest with the mining people. (On the subject of rock mechanics, papers will be by invitation only.)

71. A Symposium on Rock Mechanics Related to Caverns and Pressure Shafts was announced for 26-28 May 1982 at Aachen. The Board agreed to give sponsorship to the meeting. The Board further recommended the 1982 Council meeting be held at the conference, subject to affirmation by the Council in accordance with the ISRM bylaws at the 1981 Council meeting in Tokyo.

72. Ken Mathews (Canada) announced a conference on Mechanical Excavation of Rock to be held in Canada in May 1982. The conference will be

cohosted by the University of British Columbia and the Canadian International Tunnel Association (ITA) group. The event will be sponsored by the ISRM. He stated that Canada wanted to invite the Council meeting to be held in conjunction with that meeting but apparently had been preempted by the Board recommendation to go to Aachen in 1982. He also announced an intent to invite the Sixth International (1987) Congress of Rock Mechanics to Canada. (The invitation is at present improper according to statutes. The invitation should be formal and presented to the Council in 1983 at Melbourne, unless, as later discussed, the statutes are modified in 1981 or 1982.) (Note: I believe such modification is useful to give a host nation as much time as possible in preparing for forthcoming Congresses. I recommend that the U.S. National Group so indicate our support by letter to the ISRM Secretariat.)

73. The 23rd U.S. Annual Symposium for Rock Mechanics to be held at Berkeley will be officially sponsored by the ISRM. By such sponsorship, the ISRM lends its name and prestige in the hopes of making the symposium more attractive to participants and more international in attendance. Prof. Atchison stated the sponsorship of noncompeting conferences (i.e., Aachen, Canada, and Berkeley) poses no problem. (Note: Further conversation with Bill Judd indicated that sponsorship carried certain requirements, i.e., translation services, preprints, reduction in fees to ISRM members, etc.)

74. Prof. E. T. Brown announced preliminary plans for the British Geotechnical Society to host a Symposium on Applications of Rock Mechanics in Deep Mines in 1984. The program at this time is intentionally vague since it will be held after the 5th Congress in Australia, and Prof. Brown and his colleagues wanted to wait until the Congress program was announced so their program would supplement and complement the Australian program. He announced the intent to invite the Board and Council to the meeting for 1984. (Note: I suggest that the Vice-President for North America write a letter to the President and Secretariat stating that North America would like to host the 1985 Board and Council meeting of the ISRM. At the present time, I suggest further that the letter be intentionally vague about the location and timing of

the meeting, especially since Canada and the United States have not formulated firm plans that far in advance and do not know at this time about the vitality of the rebirth of the Mexican national group.)

75. Bill Bamford described work progressing to the holding of the 5th International Congress for Rock Mechanics in Melbourne, Australia, in 1983. The Council was polled with respect to suggested starting dates. The period of 10-15 April was agreed upon. (All delegates except the United States requested "mid-April" as the most convenient. The United States had previously responded by cable suggesting the last week in March as more convenient than the dates agreed upon because of the start of preparations for final exams at many universities.) The themes of the Congress were discussed. The themes presented had been discussed at meetings of the hosting societies. As major themes, applications of rock mechanics to mining projects were emphasized, and as minor themes, basic principles of rock were emphasized. While no dissenting opinions were offered, it was suggested strongly by Fumigalli (Italy) that the national groups should have been polled to indicate interest and to have some say in the final discussions. (Note: It is suggested that the USNC/RM write Bamford a letter expressing support and understanding of the difficulties of arriving at a program compatible to everyone's wishes. We should emphasize our 18-month study of research needs and say that in our opinion the major and minor themes cover a majority of topics under study and should, therefore, be of interest to potential United States participants. Private conversations with Wittke indicated his concern that many of the people interested in rock mechanics in the European community would be distracted by the present alignment of proposed major/minor topics. Wittke suggested that since this is a "transition" Congress intended to bring mining interests more to the forefront, it might be more advisable to swap the emphasis on major/minor themes to show strongly that civil and mining engineers have much in common, thus emphasizing basic rock principles as major themes, and then move to sessions indicating applications in mining engineering as minor themes.)

76. Dr. Silverio stated that a four-year preparation for such major

conferences as the Congresses of the ISRM is not adequate. He stated that the ISSMFE had an eight-year lead time. He indicated that a change in the ISRM statutes would be proposed at the next Board/Council meeting. (As discussed earlier, I believe the United States should support the proposed change.)

77. The Council voted to hold the 1981 Board/Council meeting in Tokyo in 1981 in conjunction with the International Symposium on Weak Rocks. The date was stated as 20 September 1981 for the Council meeting. Some discussion was voiced by the European representatives questioning whether or not a quorum would be present in Tokyo. Dr. Silverio responded with a sincere and logical argument supporting a decision to move to areas other than Europe so as to make the ISRM truly an international organization.

78. The meeting was closed with no other business.

23 June; Stockholm, Sweden

79. ROCKSTORE 80 opened (Bibl: 34). The purpose of the symposium was to emphasize three major considerations in placing facilities underground.

a. Environmental Protection. In this theme, papers, reports, and discussions centered on urban growth by addressing means of making the city more efficient, protecting the city environment, and facilitating urban expansion.

b. Low-Cost Storage. In this theme, papers, reports, and discussions centered on the need for well-protected, low-cost storage facilities to reduce the differences between production and consumption in view of possible crises, natural disasters, and famines. The Scandinavian experience obtained over the past 30 years in storing oil and gas in rock caverns was highlighted.

c. Energy Saving. In this theme, papers, reports, and discussions noted that the earth's surface insulates the subsurface from periodic changes in temperature. The subsurface can be used to reduce the demand for prime energy in heating and cooling.

80. The conference was opened by H. M. King Carl XVI Gustave of Sweden. Mr. Brand read a message from H. E. Dr. Kurt Waldheim, the United Nation's Secretary General. (The Swedes really know how to start a

conference off with an impressive flourish.) The program (Bibl: 35) was: General Session 1, Environmental Protection; General Session 2, Low-Cost Storage; General Session 3, Energy Savings; Round Table Session 1, Environmental Protection; Round Table Session 2, Low-Cost Storage; Round Table Session 3, Energy Savings; Special Session, Nuclear Waste Disposal; Special Session, Energy Production, Distribution, and Conservation Underground; Special Session, Subsurface Construction in Less-Developed Regions; Special Session, Subsurface in Metropolitan Areas; Special Session, Subsurface Storage; and Closing Session.

81. The General and Special Sessions consisted of papers, questions and answers, and discussion. The Round Table Sessions generally consisted of discussions from a chairman and a panel of experts with one member of the panel giving a presentation on the global aspects of the subject theme followed by a presentation by the other panel members summarizing state-of-the-art reports from the official delegations. Selected nations made oral presentations from their state-of-the-art reports; the Round Table Sessions ended with open discussion by representatives of the official delegations (Bibl: 36).

82. The ROCKSTORE 80 Symposium was held at the Stockholm International Fair (Massan) premises. The building and grounds are especially well equipped to host such a meeting. The ROCKSTORE 77 Symposium had attracted some 1500 delegates; the ROCKSTORE 80 Symposium was attended by a far less number (I heard about 850 (Bibl: 37)). The decrease in attendance was attributed to the fact that no major breakthroughs had occurred in the last three years. I found, however, the program new and beneficial. A list of papers appearing in the proceedings is shown in Bibl: 38.

83. Six technical tours followed the ROCKSTORE 80.

84. The delegates and accompanying persons were invited to attend a reception given by the City of Stockholm at the Stockholm City Hall. The building was built in 1923 and is the location of the annual awarding of the Nobel Prizes.

85. More than 80 companies had exhibits showing or demonstrating equipment or explaining their operations. The exhibits were particularly

beneficial to me in that it gave me a chance to obtain quite a supply of literature and to engage company officials in conversation. A list of exhibitors is given in Bibl: 39. On this day I toured the exhibition hall to get an idea of available information and to obtain literature for study.

86. Significant information was obtained as follows:

a. Material from VIAK, an independent Swedish consulting firm, who lists planning for rock caverns as one of their specialties (Bibl: 40 and 41).

b. The Swedish consulting firm AIB provided material that describes their system of photogrammetry and data processing that has been used to determine the volume of oil stored in about 150 caverns since 1965 in Sweden, Finland, and Norway (Bibl: 42).

c. Material from FUELSTORE indicates that it is a joint venture of three companies among which Fortifikasjon A/S (a Norwegian firm) specializes in underground storage of oil (Bibl: 43).

d. Material from F. Selmer describes the company as a Norwegian contractor for Fuel Oil Plants in Rock (Bibl: 44).

e. Material from Stabilator describes the shotcreting equipment by the Swedish company (Bibl: 45). Stabilator is part of the Skanska Group.

f. Material from John Mattson Byggnads describes the Brofjorden project on which his company is the "turn-key" contractor. When completed, the Brofjorden caverns will store 4 million m³ of crude oil (Bibl: 46).

g. Material from WP System, a Swedish firm, describes a construction technique known as Rib-in-Roc in which reinforced concrete arches are constructed to surround cavities with spans of greater than 50 to 60 m (Bibl: 47 and 48).

h. Material from Tyrens, a Swedish consulting firm (represented by Uniconsult abroad), describes a consulting job on the Nynashamn crude oil cavern (Bibl: 49).

i. The material from NAB illustrates the construction of the crude oil cavern at Gothenburg (Bibl: 50).

j. The Swedish Government had a display booth in the Exhibit Hall. Several packets of material was picked up for information purposes. These include information on the Swedish Civil Defense System (Bibl: 51), the Geological Survey of Sweden (Bibl: 52), heat storage in rock caverns (Bibl: 53), heat storage in groundwater aquifers (Bibl: 54), handling and storage of high-level radioactive wastes (Bibl: 55), a nuclear waste guide (Bibl: 56), a summary of research performed during the past 20 years by the Swedish Council for Building Research--particularly dealing with tunnels and caverns (Bibl: 57), and a manual on planning of subsurface construction works (Bibl: 58). This last document will be of particular interest when the Regional Petroleum Reserve Study is resumed. (The host of the exhibit while I was visiting was Mr. Carl Anderson. He indicated that he was planning to visit the United States in late July. He had heard of work being conducted at the WES and would like to know the procedures for coming. I indicated that he should work through the Swedish Embassy. If he comes, he is extremely interested in obtaining information on the WES study of Flow of Water Through Rock Masses.)

k. Literature from the Rock Tank Group, a joint venture concerned with consulting, tunneling, and constructing "turn-key" projects in underground oil storage (Bibl: 59).

24 June; Stockholm, Sweden

87. I met with representatives of GEOSTOCK including: Mr. Andre Clerc-Renaud, President; Mr. Jacques F. Charie, Marketing Manager; Dr. Vincent Maury; and Mr. Gerard Fontan.

88. GEOSTOCK is jointly owned by Societe Francaise des Petroles BP, Elf Union, Shell Francaise, and Compagnie Francaise de Raffinage (Total). The company and its subsidiaries were formed with the aim of studying, constructing, owning, in whole or part, and operating underground storage facilities of various types. They conduct their own research into geotechnical matters, blasting and drilling, and types of products and energy that can be stored. Material describing Geoscience are Bibl: 60 and 61.

89. The GEOSTOCK representatives were familiar with the Strategic Petroleum Reserve (SPR) Program of the DOE. This familiarity was gained

as a subcontractor with BDM Company of McClain, Virginia. In that association, they had been asked to make revisions to the overall plan and to provide general criteria for solution mined caverns and abandoned mines. The study was to center on spacing of caverns, quality of product, etc. A "first increment" had been completed on the subcontract, but the study has not been completed since the DOE is reconsidering the SPR Program in view of the inability to purchase crude oil. Dr. Maury expressed caution concerning the Bryan Mound, West Hackberry, and Bayou Choctaw cavities in salt domes--mainly due to their size. He also mentioned that the Weeks Island facility had not been adequately tested, to his satisfaction, in the upper level. He mentioned a roof collapse in a limestone mine owned by Fenix and Scissons (site not given) in a similar manner as an abandoned iron mine owned by GEOSTOCK. He thought the mechanism might be related to pore water pressure distribution in the mine roof.

90. They mentioned an underground rock cavern, the first to be built in North America to store fuel oil. The plant will operate on the fixed-bed principle and is being built at a depth of between 150 and 200 ft in limestone for the owner, Ontario Hydro at Wesleyville (Bibl: 61).

Construction was stopped after the access tunnel was driven. Some 3.2 million bbl of residual oil was planned for storage. (Later correspondence with Dr. C. F. Lee of Ontario Hydro indicated the project was halted in 1979 because of a reduction in electrical power demands and the price of fuel oil. At that time, excavation for the access ramp and some 70 percent of the access tunnel had been completed. Present studies are being made for conversion to a coal-fired facility.)

91. Significantly GEOSTOCK had planned a facility in which the fuel oil could "freeze" or congeal during periods when the fuel was not needed. (This is the only example I could determine of this plan of operation.) Reheating was to be accomplished by circulating hot water on top of the congealed residual oil to cause "erosion" of the surface to eventually reach the bottom of the caverns, which was to be constructed on a 1-percent slope to facilitate collection and separation of the oil and water. The planned operation had been simulated by the use of physical

models. The project (at Vexin) was abandoned--as discussed later.

92. GEOSTOCK is now building a fuel oil storage facility (continuous heating) for South Korea. (No other information was given.) They evidently quite often use abandoned mines for storage in general but not for residual fuel oil. Here they save construction costs but may have to invest in the cost of strengthening portions of the mine. They mentioned that abandoned mines must be checked to determine if the product will be affected by the rock (ore). The mines must be deep enough to ensure a hydrostatic pressure to prevent migration of the product. Finally mining must have been in such a manner that the long-term stability of the caverns can be assured.

93. They spoke of demonstration projects to gain public acceptance of the technique. They suggested that the access tunnel can be part of the final construction, which would reduce the construction contract cost. Furthermore, the demonstration project will allow large-scale in situ tests to be performed to help in making decisions on the construction of the caverns. They had performed such a demonstration at Vexin, a 800,000-bbl storage facility in chalk. Here the groundwater is used as a water supply, and there were expressed fears that the drinking water would become contaminated; so far in the three-year operation, the oil content in the groundwater has always remained lower than 1 ppm. The Vexin project was mentioned also as an example of GEOSTOCK's ability to design and build caverns in weak materials (unconfined compressive strength approximately 800 psi). Although construction was by Skanska, this ability is a result of extensive rock mechanics tests, interpretation, and analysis. This type project indicates a major departure from the "turn-key" approach offered by the Finns and the Swedes. They stated that the geologic conditions were so uniformly good in the Scandinavian countries that contractors would accept the small risks involved. However, in France (and other places) the geologic conditions vary significantly so that the contractor expects the owner to accept the risk. (Skanska accepted the contract responsibility on a unit price basis.)

94. Dr. Maury mentioned a paper in the Third International Congress

(Denver, 1974) in which he described GEOSTOCK's geophysical approach to use acoustic devices (frequency content of the noise) to determine roof falls. In one case, a collapse was predicted 24 hr in advance; in another case, a collapse was predicted 5 or 6 days before failure. The GEOSTOCK personnel are so confident with the approach that they are now using this approach as a monitoring device. Dr. Maury will have a paper in either the July or August issue of The Oil and Gas Journal that describes methods of determining the water tightness of caverns. The GEOSTOCK brochures on a sonar survey system to determine cavern size and a description of a petrophysical model are Bibl: 62 and 63, respectively.

95. GEOSTOCK is represented in the United States by: Mr. R. F. Langill (Dick), P. O. Box 357; Germantown, MD; Telephone 301-972-2979 and Telex 901828 Hamel Ale.

25 June; Stockholm, Sweden

96. I met with SWECO representatives: Mr. Johan Theorell, Marketing Manager; and Mr. Bjorn Hamilton, Senior Transport Engineer.

97. SWECO is a consulting group (presently embracing seven member firms in Sweden) that lists among the many areas of applying its capabilities in research, planning, design, procurement, and contract administration and management, the completion of underground storage of residual oil. Our conversation indicated that they had largely abandoned steel tank farms as an effective means of storing residual fuel oil. This fact was emphasized because in Scandinavia where the bulk of their experience rests, the rock conditions are very good, and secondly, because most storage systems are larger than $100,000 \text{ m}^3$ (where they consider the underground storage to be more economical). They indicated that initially they had constructed four or five facilities along the line of the U.S. Red Hill facility in Hawaii (i.e., steel-lined underground caverns), but presently the steel lining had deteriorated (bad steel produced after World War II was cited as the reason). They were taking the philosophy that the lining was not needed anyway so they were drilling holes in the lining and converting the facilities to the equivalent of fixed-bed unlined cavities. They thought the first facilities in Sweden for fuel oil storage were the abandoned mines; however, no

specific reference could be recalled. All their facilities have operated on either the fluctuating or fixed-bed principle with no dry-bed operation. They reported knowledge of problems with bacteria growth at the oil/water interface but have no reference to a published paper. They indicated that residual fuel oil had been stored for 10 to 15 (?) years (always heated and cycled) without problems. They indicated that explosions or fires had never been a problem with any of their facilities, but last year one facility had been overfilled when a valve failed. They cited the Japanese plan to build a demonstration project in order to attain public confidence as a useful first step in introducing the concept of underground storage to a new country.

98. At present, SWECO has a North American representative, who is being phased out. SWECO is now encouraging joint venture relationships in North America.

99. Materials obtained from SWECO are Bibl: 64-68.

26 June; Stockholm, Sweden

100. I met with SKANSKA representatives: Mr. Hakan Bertland, Project Manager, and Mr. Lars Soderberg.

101. The SKANSKA Group is a leading Swedish contractor that works in many technical fields but cites consultation, feasibility studies, preliminary design studies, principle design work, and construction activities as part or complete services offered. Several residual fuel oil projects, as well as "turn-key" operations, are listed among the Group's accomplishments (Bibl: 69 and 70).

102. In discussions concerning the length of storage without replacement, they indicated 10 years as the limit to their knowledge. They also said that they had served as the contractor (on a unit price basis) with GEOSTOCK to build an underground residual fuel oil cavern in chalk that was to be allowed to cool down or congeal (i.e., the Vexin project). Then (according to SKANSKA), GEOSTOCK miscalculated the quantity of water inflow, and the site was converted to a liquid petroleum storage facility.

103. They indicated that with the exception of two or three cases, they do not own their facilities--again the emphasis on "turn-key"

construction. Most activity now is in construction of caverns for crude oil storage with sharing of the facility with the government.

104. They mentioned that they had worked directly with the DOE until August 1979 in performing a design study for a mined underground cavern for crude oil (under the SPR program) to be located in Portland, Maine. When the SPR program was delayed, their contract was terminated. There were discussions with U.S. Government officials about continuing the design/construction with Government sponsorship but converting to storage of residual fuel oil. Evidently, the talks produced no results. They also mentioned the submittal of a proposal to New Bedford, Connecticut, for an underground cavern--again apparently without results.

105. Insofar as why Norway and Denmark appeared to be the exception to Sweden and Finland in going to underground storage, they cited that there were no oil fields in Sweden and Finland, the ports were not open all year with heavy oil dependence in the winter months, and the rock conditions are not as good in Norway and nonexistent in Denmark. They also indicated that Norway has developed the hydroelectric capability of the country to a great extent.

106. They discussed the approach to be taken in areas where the rock conditions may vary from Sweden/Finland and where data concerning the underground behavior may be insufficient for proper design. In that case, they would proceed carefully with geotechnical investigations and emphasized that a pilot project, like the one planned by the Japanese, would not only serve as a public demonstration but would also allow final design data to be collected. They mentioned such an in situ test arrangement in Switzerland in a limestone formation.

107. The good rock conditions in Sweden make the decision rather easy to go underground. Also because sound bedrock is so near the surface, access tunnels on 1:7 or 1:10 slope is preferred to shafts. In the case of access tunnels, they are sized sufficiently that the large underground machines can be put to work to reduce construction costs.

108. On the question of allowing the residual fuel oil to congeal, they reemphasized the only involvement to date was construction of the Vexin facility. They did mention that an oil--Russian 10 (pour point minus

10°C)--was classified as a fuel oil and consideration could be given to use of residual fuel oils other than No. 6.

109. Even though the Swedish Government controls a portion of the storage volume for strategic purposes, no thought is ever given to allowing for the material to congeal or to remain uncirculated. Facilities are shared. In particular, the Swedish National Board of Defense dictates that a certain percentage of the fuel oil must be in storage on 30 September of each year for emergency use by the state. In case of any emergency, the Government would assume control of all the oil and direct its distribution. The owner of the facility thus cycles the oil and during the winter months uses about 10 percent of the reserve volume required by the Government.

110. All facilities designed by SKANSKA are of the fixed-bed type, but the new direction is with a dry bed. In their thinking, the elimination of the oil/water interface eliminates the buildup of slime (or bacteria). The slime causes problems with pumps and acts as an insulator if water is being used to keep the oil heated (indirect method). Also, the slime at times causes problems with the operation of the pump and sensors. They first used the indirect method for earlier grades of fuel oil that required heating to between 30° and 40°C. In fact, the slime only started appearing with the later grades that required heating to 55° to 60°C. They initially used both indirect and direct heating and then changed to direct heating only. The switch to only direct heating resulted from the insistence of one client to continuously cycle the oil. In the client's experience with steel tanks, the constant agitation of the oil prevented deposits from forming. With direct heating, they do not now see the need for the water bed (hence dry bed), but such a system will be considered on a case-by-case basis. A base of poor grade, unreinforced concrete is requested by some clients but to the personnel of SKANSKA is really not needed. The only advantages they see are the facilitated cleaning of the cavern if it is to be converted at a later date to another usage and elimination of any water pockets by a smooth concrete floor.

111. They indicated that they generally expected about 1 m³/hr of

infiltration for each 100,000 m³ of storage. The quantity is not critical, and even 10 m³/hr could be simply handled by increased capacity pumps.

27 June; Vasteras, Karlstad, Sweden

112. Tour of Central Sweden--ROCKSTORE 80 (Bibl: 71).

113. Vasteras is a town of about 125,000 people, which relies heavily upon shipping for its economic well being (Bibl: 72). The town is connected to the Baltic Sea through the Sodertalje Canal, which has been deepened along a route through Lake Malaren. The thermal power plant is one of the largest producers of electricity in Sweden. In addition, the plant supplies more than 98 percent of the houses in the city as well as many industrial plants with district heating. The centralized plant thus has but one smoke stack to control or minimize air pollution. The heating pipes are laid under streets so that their warmth prevents the buildup of snow and ice during the winter. The plant is fired by oil imported from the Baltic--hence, the importance of the canal, etc. Underground residual fuel oil storage has been used for firing the plant; the oil is stored in a 10-year-old 300,000-m³ cavern.

114. SKANSKA is now constructing two caverns with a total volume of 180,000 m³ to store diesel fuel oil as part of the strategic reserve for the National Board of Economic Defense with partial ownership by SKANSKA (Bibl: 73). The facility is being constructed in a granite gneiss but of poorer quality rock than normal. As a result, the span has been reduced to 16 m rather than the usual 20 m. The groundwater level is assured by the lake level. Regulations require the highest level of storage to be about 5 m below the lowest groundwater level. The elevation of the crown will be about -17 m. Grouting at times is used to reduce the groundwater inflow, which at Vasteras is estimated to be about 1 m³/hr. A Government regulation requires that the volume of oil be controlled so that in case of pump problems three days of uncontrolled seepage can be accommodated. The water will go through a treatment plant before being returned to the lake. Submersible pumps rated at 120 m³/hr will be used to pump the diesel fuel. Excavation rock is being used for reclamation of land in the harbor area (Photo 30). The caverns are

vented directly into the air since vapors from diesel fuel and air can never reach a critical level.

115. Cost estimates are 100 Sk/m³ total for finished cavern plus all equipment. Storage costs are estimated at 20 Sk/m³/annum. Operation costs are estimated at 1 Sk/m³ for pumping diesel fuel in and 2 to 3 Sk/m³ for pumping fuel out.

116. One of the two chambers will be entirely owned by the Swedish Board of Economic Defense with no plans to cycle the fuel. Experience has shown that diesel fuel can be stored for 10 to 15 years without any problems.

117. In the tour of the excavation, we witnessed a three-drill jumbo simultaneously drilling for placement of production rounds on the first level horizontal bench in one cavern (Photos 31 and 32). In the second cavern, 3- to 5-ton dump trucks were being used in the mucking operations.

118. Visit to FFV-Zakrisdalsverken in Karlstad. The Zakrisdal plant is organized under the Swedish Department of Industry, Ordnance Division, and produces defense material (detonators, cartridges, fuses, etc.) in both above-ground and underground plants (Bibl: 74). The underground area is about 14,000 m² with a volume of about 70,000 m³. About 100 people work underground. Individual chambers are approximately 15 by 50 by 5 m. The rock material was not particularly good, and construction was in keeping with construction practice of the 1950's (i.e., rock bolts without shotcrete protection). As a result, protection from roof falls is given with wire netting, and scaling is conducted every two or three years. Groundwater seepage into the chambers is about 400 m³/day. Seepage water is pumped directly back into the lake; sewage is pumped to Karlstad for treatment.

119. Air is changed twice an hour with a near-constant temperature of 20°C; the humidity varies from 50 percent in the summer to 70 percent in the winter. Despite this near-balanced environment, the operators report a problem in inducing new workers to go underground. However, after a two- to three-week adjustment period, they report the workers are well satisfied and tend to become loyal employees.

28 June; Falun, Sweden

120. Visit in Falun Copper Mine (Bibl: 75 and 76). The mine is owned and operated by Stora Kopparberg one of Sweden's largest companies with combined minor holdings of mining and steel-making but major holding of forest operations, including pulp and paper making and hydropower production. Mining was started toward the end of the first 1000 AD; literature that is preserved contains a description of the mines in the 13th century. The mine received charters from Swedish kings beginning in 1347. At one time (in the 17th century), the mine produced two thirds of the world's copper and was the major if not dominant economic force in Sweden. Presently the mine is producing small amounts of gold, silver, lead, and zinc from a small open-pit operation and underground works.

121. The interest is going underground in a 180-ft-deep shaft and walking through the galleries where mining methods employed since the middle ages can be seen.

29 June

122. Falun to Stockholm; Stockholm to Vicksburg.

Appendix B: Photographs

Photo 1. Entrance to
Tempeliaukio Church,
Helsinki, Finland

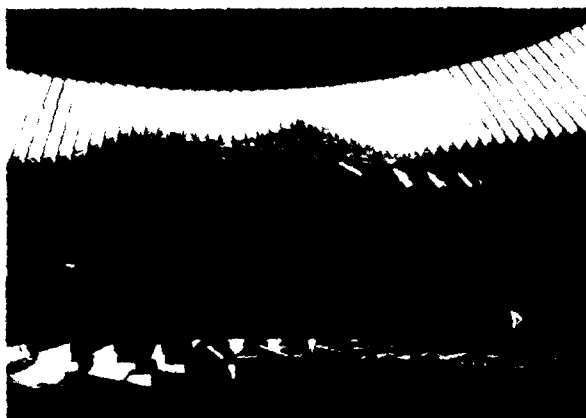
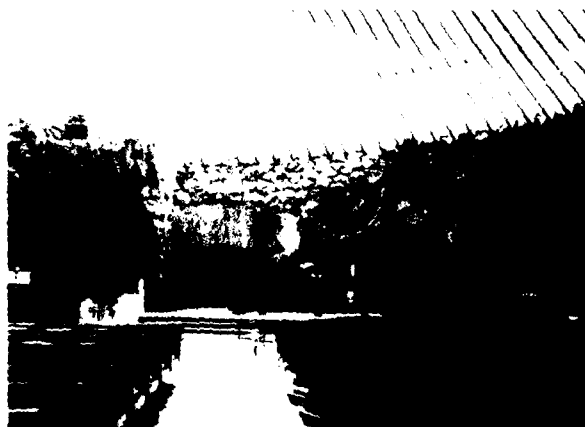


Photo 2. Interior of
Tempeliaukio Church,
Helsinki, Finland

Photo 3. Closeup view of
interior of Tempeliaukio
Church, Helsinki, Finland



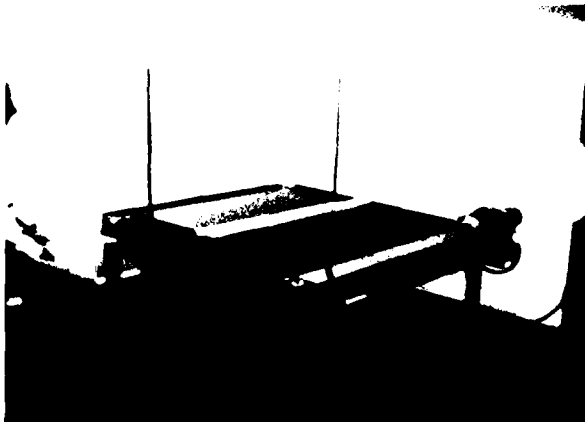


Photo 4. "Base-friction"
modeling machine at Hel-
sinki University of
Technology

Photo 5. Site of under-
ground residual oil stor-
age facility, Helsinki,
Finland



Photo 6. Control structure
for residual oil storage
facility, Helsinki, Finland

Photo 7. Entrance to
Tahkoluoto underground
oil storage facility,
Pori, Finland



Photo 8. Pumps at
Tahkoluoto underground
oil storage facility,
Pori, Finland

Photo 9. Control panel
at Tahkoluoto underground
oil storage facility,
Pori, Finland

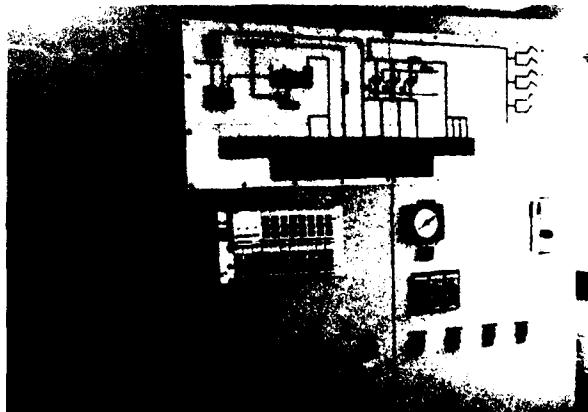




Photo 10. Equipment room
Tahkoluoto underground oil
storage facility, Pori,
Finland

Photo 11. Skimming opera-
tion Tahkoluoto under-
ground oil storage facil-
ity, Pori, Finland

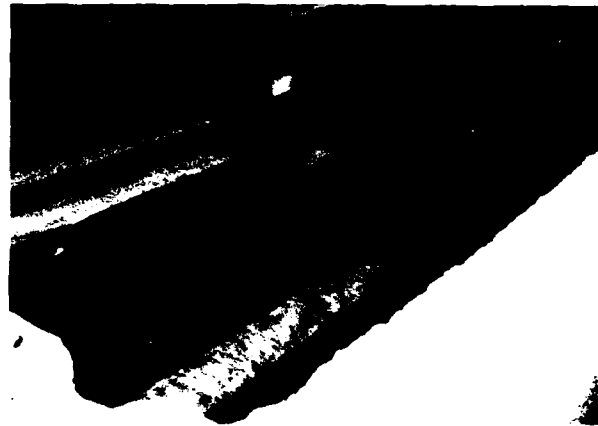


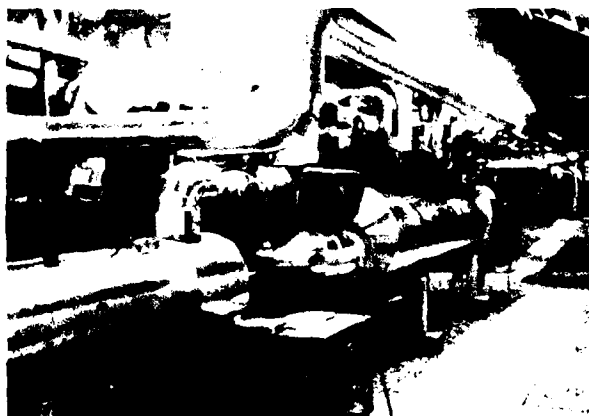
Photo 12. Access tunnel
Tahkoluoto underground
oil storage facility,
Pori, Finland

Photo 13. Oil storage tanks
existing over the Tahkoluoto
underground oil storage fa-
cility during construction,
Pori, Finland



Photo 14. Entrance to
underground oil storage
facility, Rauma-Repola Oy,
Rauma, Finland

Photo 15. Equipment room
and civil defense shelter,
Rauma-Repola Oy, Rauma,
Finland



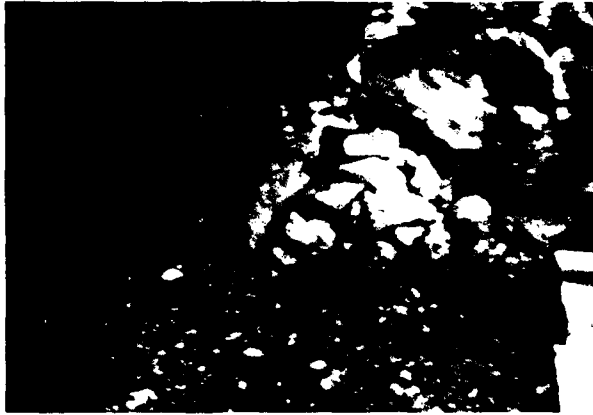


Photo 16. Rock spalls,
Rauma-Repola Oy, Rauma,
Finland

Photo 17. Location of a
second underground oil
storage facility, Rauma-
Repola Oy, Rauma, Finland



Photo 18. Residence over
entrance to underground
oil storage facility,
Rauma-Repola Oy, Rauma,
Finland

Photo 19. Exterior to Red
Hill sewage treatment plant
Rauma, Finland

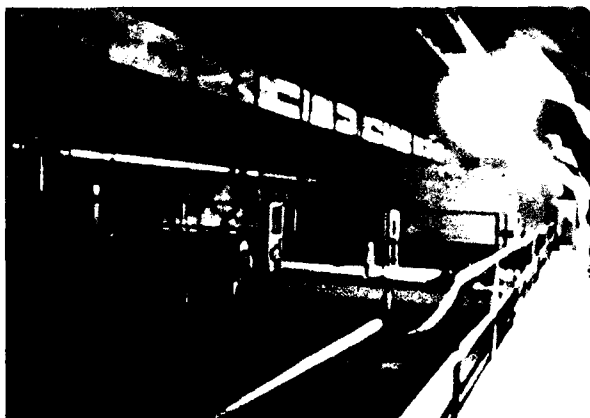


Photo 20. Underground
sewage treatment plant,
Raisio, Finland

Photo 21. Entrance to
Myllyahde Traffic Tunnel,
Turku, Finland



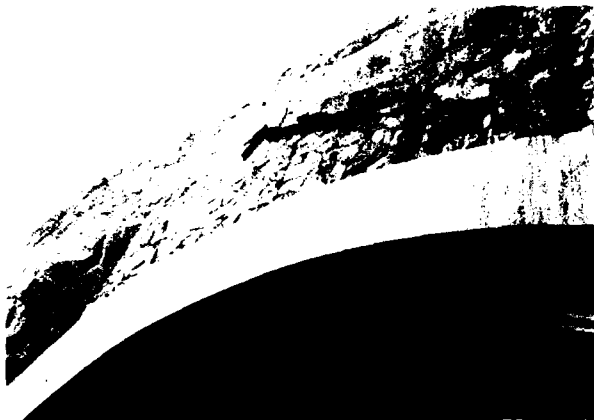


Photo 22. Crown of
Myllyahde Traffic Tunnel,
Turku, Finland



Photo 23. Blasted rock to
the right of the entrance
to Myllyahde Traffic Tunnel,
Turku, Finland



Photo 24. Site of civil
defense structure for
11,000 people, Turku,
Finland

Photo 25. Pumping station
for underground chamber
U-16, Skoeldvik Oil Refinery,
Porvoo, Finland

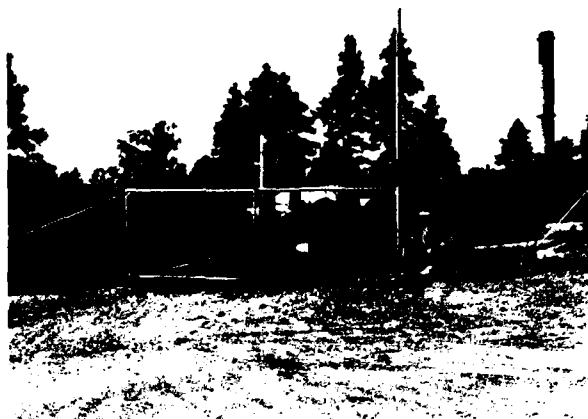


Photo 26. Vent installa-
tion for underground cham-
ber U-16, Skoeldvik Oil
Refinery, Porvoo, Finland

Photo 27. Dry well pump
facility for two underground
chambers, Skoeldvik Oil Re-
finery, Porvoo, Finland





Photo 28. Access tunnel,
new chamber construction,
Skoeldvik Oil Refinery,
Porvoo, Finland



Photo 29. Wall conditions
in access tunnel portal,
Skoeldvik Oil Refinery,
Porvoo, Finland

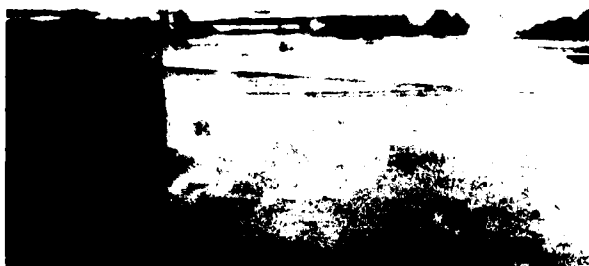


Photo 30. Land reclamation
with excavation material
from underground diesel fuel
oil facility, Vasteras,
Sweden

Photo 31. Jumbo drill
operating in underground
diesel oil facility,
Vasteras, Sweden



Photo 32. Vent hole in
underground diesel oil fa-
cility, Vasteras, Sweden

Appendix C: Bibliographic Material

General

1. Crude Oil Historical Data for U. S. Army Engineering (Sic) Waterways Experiment Station Furnished May 1980 (courtesy of Fenix and Scissions, Inc., Tulsa, Oklahoma).

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 - d). Detailed Schedule for Underground Oil Storage Plant at Tahkoluoto, Pori.
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73. Diesel Fuel Oil Stone in Vasteras.
74. FFV Zakrisdalsverken in Karlstad.
75. The Falun Copper Mine.
76. Falun Copper Mine.

Appendix D: Names and Addresses of Contacts

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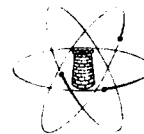
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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Banks, Don C

Storage of residual fuel oil in underground unlined rock caverns / by Don C. Banks. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1980.

18, [82] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; GL-80-19)

Prepared for U. S. Army Engineer Division, Huntsville, Huntsville, Alabama.

1. Cavities (Underground). 2. Fuel storage. 3. Oils.
4. Storage tanks. I. United States. Army. Corps of Engineers. Huntsville Division. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; GL-80-19.

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